NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

MISSILE TOTAL AND SUBSECTION WEIGHT AND SIZE ESTIMATION EQUATIONS

by

John B. Nowell Jr.

June, 1992

Thesis Advisor: Conrad F. Newberry

Approved for public release; distribution is unlimited.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) 033	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

MISSILE TOTAL AND SUBSECTION WEIGHT AND SIZE ESTIMATION EQUATIONS

12 PERSONAL AUTHOR(S)
Nowell Jr., John B.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ____ TO ____	June 1992	187

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S.Government

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Missile weight estimation, Missile size estimation, Missile subsection weight/size estimation, regression analysis

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This study utilizes regression analysis to develop equations which relate missile overall and subsection weights and geometries, including wings and fins, to variables which are considered to be the input for a new design in the conceptual or preliminary design phase. These variables include packaging requirements such as maximum length, diameter, and weight, as well as performance characteristics such as mission and range. Data for the analysis was collected from a variety of military, industrial, and academic sources.

The generic missile is split into three subsections: propulsion, guidance and control, and warhead. Utilizing single and multi-variable regression analysis, weight estimation equations are developed for the total missile, subsections , and wings/fins based on categorizing the missile by mission: air-to-air, air-to-surface, surface-to-air, or surface-to-surface; and by range: short, medium, or long. Measures of fit are developed and displayed with their associated equations to aid in selection of the optimum equation.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Conrad F. Newberry	22b TELEPHONE (Include Area Code) 408-646-2892 22c OFFICE SYMBOL AA/Ne

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603 Unclassified

Approved for public release; distribution is unlimited.

Missile Total and Subsection Weight and Size Estimation Equations

by

John B. Nowell Jr.
Lieutenant, United States Navy
B.S., United States Naval Academy, 1984

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN ENGINEERING SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
June 1992

Author: John B. Nowell Jr.

John B. Nowell Jr.

Approved by: Conrad F. Newberry

Conrad F. Newberry, Thesis Advisor

G H Lindsey

Gerald H. Lindsey, Second Reader

David J. Collins

Daniel J. Collins, Chairman
Department of Aeronautics and Astronautics

ABSTRACT

This study utilizes regression analysis to develop equations which relate missile overall and subsection weights and geometries, including wings and fins, to variables which are considered to be the input for a new design in the conceptual or preliminary design phase. These variables include packaging requirements such as maximum length, diameter, and weight, as well as performance characteristics such as mission and range. Data for the analysis was collected from a variety of military, industrial, and academic sources.

The generic missile is split into three subsections: propulsion, guidance and control, and warhead. Utilizing single and multi-variable regression analysis, weight estimation equations are developed for the total missile, subsections, and wings/fins based on categorizing the missile by mission: air-to-air, air-to-surface, surface-to-air, or surface-to-surface; and by range: short, medium, or long. Measures of fit are developed and displayed with their associated equations to aid in selection of the optimum equation.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND AND PURPOSE

While there has been extensive work in the field of weight estimation equations for aircraft, there has been comparatively little work done, at least in the open literature, for missiles. Since much of the work which has been done is either classified or proprietary, there is a need for weight estimation equations for missiles and their subsections which could be used in the preliminary or conceptual design phase and for trade-off studies. These estimation equations can be developed in several different ways; semi-analytically, empirically, or by utilizing a combination of the two.

The majority of the work done using the semi-analytical approach tends to be, by necessity, very specific. This approach is feasible only on a computer, is normally applicable only to the overall missile body or to a specified component of a subsection, and requires a detailed knowledge of design criteria such as loads, moments, and stresses which may not be known early in the design process. An example of this type of analysis is embodied in Vought Corporation's Missile Integrated Design and Analysis System, MIDAS, which estimates missile body weight.(Atkinson, 1982,p. 1) While

this approach is certainly the method of choice during the latter stages of design, it may not be easy or quick enough for a first approximation of the missile's total and subsectional weights and sizes.

An empirical approach using statistical regression analysis of historical missile data seeks to develop equations for the different physical properties of the missile and its subsections based on the rationale that since these parameters were justified during each previous missile's own design process, relations obtained using the data should be applicable to new designs. Obviously, the missiles must be grouped in some logical manner which ensures similarity between the missile being designed and the missiles used in the development of the weight equations. Previously, the data base for missiles may have been too limited to provide statistically significant relationships, but today with the multitude of operational and historical missile systems weight and size data available, the use of an empirical approach is feasible.

Another method which has received attention is the use of both approaches in a method called constrained regression analysis. This approach develops a statistical weight estimation equation again using regression analysis, but it constrains constants, exponents, and other factors to fall within a desired range which is determined semi-analytically.(Staton, 1969,pp. 1-9) Therefore, this approach

also tends to have a narrow focus and requires some knowledge of the design parameters which may not be known early in the conceptual design phase of a project.

The focus of this work will be to utilize the empirical method of statistical regression analysis to develop equations which relate overall missile and subsection geometries and weights to design variables which are considered to be the input for a new design in the preliminary stages of development. These variables include packaging requirements such as maximum length, weight, and diameter in addition to performance characteristics such as mission, range and, in some cases, speed. The generic missile will be broken down into three subsections; propulsion, guidance and control, and the warhead. In order for this work to remain unclassified, the level of specificity will remain at the subsection level, and specific components in each subsection for each missile will not be identified. However, typical components within a generic missile's subsections will be discussed. Because subsectional data is not available in the open literature, a world missile data base will be assembled with the overall missile physical and performance characteristics discussed above. Another data base composed of U.S. missiles and containing the same type of information for the subsections will also be assembled. Single and multi-variable regression analysis will then be applied to each data set, after

appropriate grouping, in order to develop useful design equations.

B. CLASSIFICATION OF MISSILE

1. Mission Type

a. Air-to-Air Missile(AAM)

The air-to-air missile, or AAM, is a missile which is fired from one aircraft and targeted against another aircraft or missile. It is generally a relatively small missile due to the load constraints of the carrying aircraft and the oftentimes shorter range requirements. The propulsion is normally provided by a solid propellant rocket motor with a boost-glide type profile. For longer range or greater speed applications, a sustainer rocket motor may be included.(Chin, 1961,p. 4) While solid and liquid fueled ramjets have been developed for quite some time, there have been few tactical missile systems which have used them despite their considerable merits. While early versions tended to beam ride or home all the way to the target using infrared(IR) or radar seekers, newer missiles have exhibited a variety of guidance and control methods including fire and forget modes.

b. Air-to-Surface Missile(ASM)

The air-to-surface missile, or ASM, is launched from an aircraft against surface targets such as ships, tanks, gun emplacements, radar and GCI sites. Again, the load constraints of the carrying aircraft play a dominant role in the size of the missile. The range of these missiles varies greatly. The shorter range missiles tend to use some type of

solid propellant rocket motor, while longer range applications may require the use of an air breathing engine such as a turbojet. While short range ASMs may use command by carrier all the way to the target, longer range requirements may require inertial guidance prior to the terminal phase of the engagement. Thus, virtually every type of guidance and control is in operation including IR, active and semi-active radar, and TV.

c. *Surface-to-Air Missile (SAM)*

The surface-to-air missile, or SAM, is fired from a surface launcher against an aircraft or missile target. The launcher might be onboard a ship, on a mobile launch platform, or shoulder fired by a person. Normally designed for area or point defense, the missile ranges required to fulfill the missions can usually be satisfied by a solid propellant rocket motor with multi-staging included if necessary to increase the range. The guidance and control system weight varies with different range requirements. Short range requirements may be satisfied solely with an IR seeker, while longer range requirements dictate increased complexity.

d. *Surface-to-Surface Missiles*

The surface-to-surface missile, or SSM, is launched from a surface launcher against a target on the ground. Two distinct types of systems are present; strategic and tactical. Strategic systems are offensive weapons capable of carrying

payloads a great distance, such as ICBMs. Tactical systems have a much shorter range and are designed for battlefield use. It should be noted though that as the ranges of some cruise missiles, such as Tomahawk, increase the distinction becomes a bit blurred. A variety of different propulsion systems including solid and liquid propellant rockets, both single and multi-staged, as well as air breathing engines are in use based on range requirements. Short range missiles may use command control, such as optical wire guidance, all the way to the target, while longer range missiles may require inertial midcourse guidance and some type of homing for the terminal phase of the engagement such as active radar.

2. Range Designation

In addition to classifying missiles by their mission type in order to achieve similarity, they may also be classified by their maximum design range. Generally, missiles are classified as short range(SR), medium range(MR), or long range(LR). Since there is no definitive guidance as to specific numerical values for these range values the following range designations will be used for this study:

- Short Range (SR) 0 - 19 nautical miles(nm)
- Medium Range (MR) 20 - 49 nautical miles(nm)
- Long Range (LR) > 50 nautical miles(nm)

While there is no accepted standard for range designations, the values cited above generally agree with the assumptions used in the military and industry. It is important to point out that the maximum design range will be used and that the actual range of operation could vary slightly from this.

C. MISSILE SUBSECTION DESCRIPTION

1. Propulsion

The propulsion subsection of the missile encompasses the power plant, or prime mover, any peripherals required to support the plant, the nozzle, and the case body surrounding the propulsion section. For the air breathing engines considered, peripherals included the fuel, fuel tanks, auxiliary power units(APUs), and the air intakes.

2. Guidance and Control

The guidance and control subsection of the missile encompasses all of the mechanical and electronic equipment necessary to guide the missile to the target as well as the case body. The radome is included in this subsection as are any control actuators for the wings and fins. While the specific components differ according to the type of guidance used, the following equipment, in varying combinations, is included in this subsection: seeker, autopilot, gyroscope, data processor, antenna, inertial measuring unit, radar receiver/transmitter, and power supply(battery). Note that while the APU was included in the propulsion subsection, the

battery, if present, is included in the guidance and control subsection. This is primarily because of the fact that, in most cases, the battery is located with the guidance package, and the APU is located in close proximity to the propulsion package.

3. Warhead

Although this subsection is termed the warhead subsection, it actually encompasses the entire ordnance package. It includes the payload, a fuze or target detection device(TDD), a safety and arming device, and the case body. Figure 1-1 shows a simplistic arrangement of the three subsections for various current missiles (Knutsen,1992).

D. MISSILE WING/FIN DESCRIPTION

Many of the missiles had both wings and tail fins and, in some cases, multiple sets of one or the other. Although in many cases the tail fins acted as the control surfaces for maneuvering, this was certainly not the exclusive case. In determining the wing/fin variables to be used for analysis, it was deemed prudent to follow the procedure found in several sources of overall missile data which used the wing or fin with the maximum span as a benchmark for comparison. Once the wing or fin to be used for analysis was determined, specific variables and derived quantities for use in the study could be identified. Figure 2 is a schematic of a typical planform. The span is denoted by the symbol b, the root chord by Cr ,

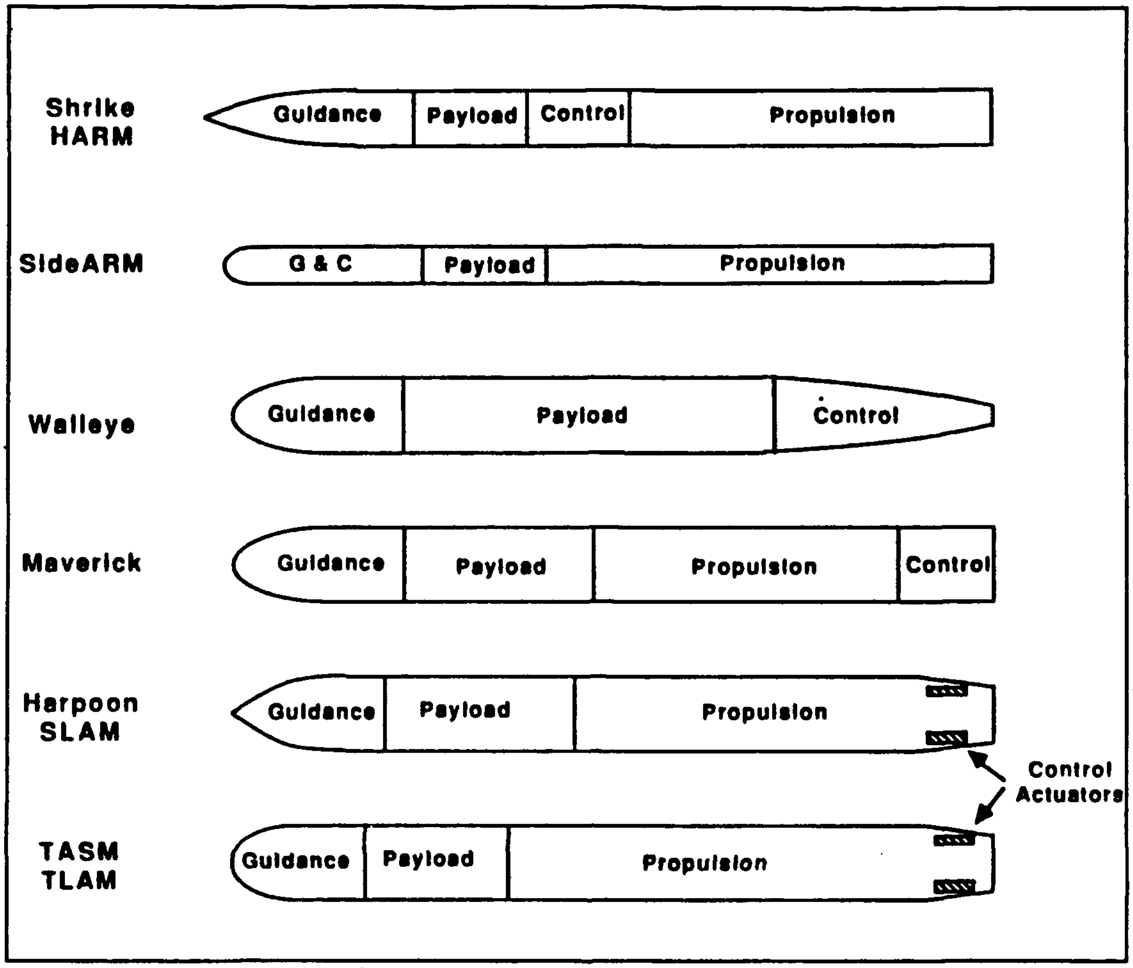

Figure 1: Simplistic Subsystem Arrangement Diagram

and the tip chord by Ct. The sweep angle is the angle between a line drawn perpendicular to the missile body and the leading edge of the wing. Since the majority of the missiles considered did not have wings or fins which remained continuous through the body of the missile, the exposed portion of the wing was selected for calculation of desired variables. The exposed span(be) is equal to the span less the diameter of the missile. The exposed span and the exposed planform area(Se) can then be used to calculate the aspect

ratio($AR = be^2/Se$). Similarly, the taper ratio(TR) was calculated using the relationship that $TR = Ct/Cr$ and taking Cr at the interface between the body and the planform.

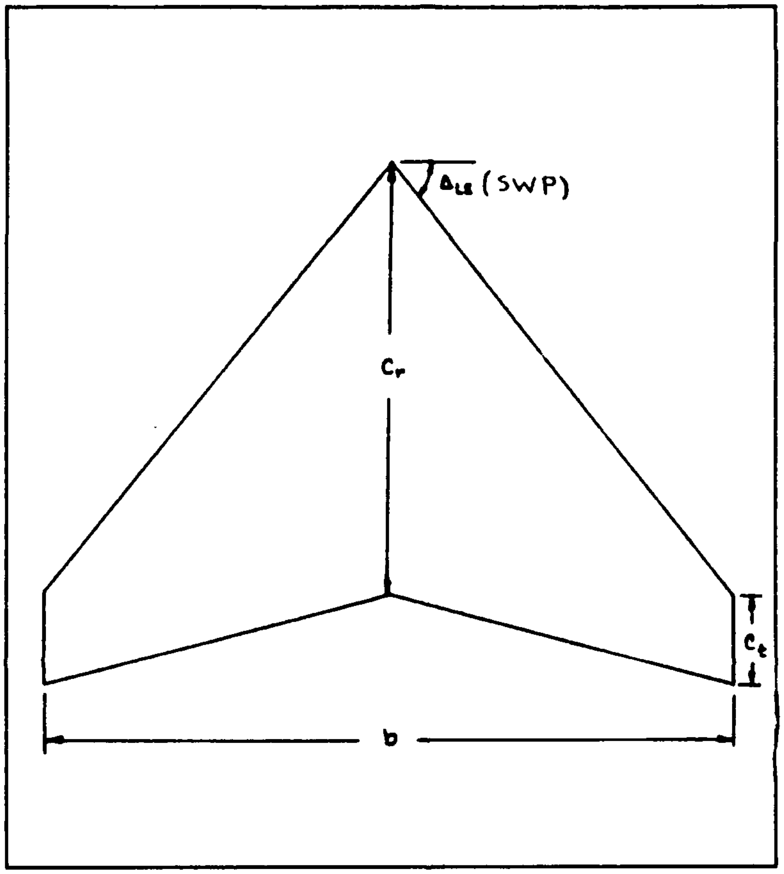

Figure 2: Planform Geometry Diagram

E. DATA COLLECTION

1. Required Data

The data desired for the analysis included all dimensions necessary to define the geometry of the body as well as the accompanying weights. These dimensions included: length, diameter, and weight for both the overall body and, when available, the subsections. Once this data was collected, the overall and subsectional volume and densities were computed. Special mention must be made of the fact that the volume is calculated on the basis of a right circular cylinder and is not the true volume in all cases such as the radome section. While it closely approximates the true volume in most cases, the detail of drawings used was not specific enough to permit calculation of the true volume. Additionally, information on mission, maximum range, operational speed, and production start was needed. Production start year was needed in order to attempt development of a guidance and control technology factor and will be discussed further. Based on the maximum range, a range designation was assigned.

In order to conduct the wing/fin analysis, the weights of the planform surfaces were required, as well as a schematic. The schematic was used to compute the sweep angle, taper ratio, exposed planform area, exposed span, and the

aspect ratio. Many times, scaling was required to compute these values depending upon the detail of the drawing.

2. Collection Sources

There is a wealth of material on the overall dimensions and characteristics of missiles in the open literature. Perhaps the best synopsis of worldwide missile systems, General Dynamic Corporation's, *The World's Missile Systems*, presents an outstanding overview of both westbloc and former eastbloc nations' missile systems. Another outstanding reference containing U.S. missiles only is Data Search Associates, *U.S. Missile Data Book*. Unfortunately, there is virtually no information available in the open literature on the dimensional specifics of any missile subsections.

One means of collecting subsectional data was to contact the industrial producer. In the case of Tomahawk, RAM and the Standard Missile family of missiles, the General Dynamics Corporation was extremely helpful. Additionally, many academic institutions play a role in weapons research and development such as the Applied Physics Laboratory(APL) at John Hopkins University and can be tapped for information. APL supplied some information on the Harpoon missile.

Different organizations within the military were able to supply the majority of the subsectional information. The most difficult aspects of this phase of the data collection were in determining the correct organizations to contact and

in ensuring that the data remained at the unclassified level. For the Navy and Marine Corps, in addition to the individual missile program offices, the Naval Weapons Center(NWC) located in China Lake, California was an excellent source of data. Specifically, the Weapons Planning Office at the Naval Air Warfare Center was able to provide data on a number of missiles. For the Army, the U.S. Army Missile Command located at the Redstone Arsenal in Alabama was the focal point for collection. Through this command, access was gained to the U.S. Army Cost and Economic Analysis Center(USACEAC) Information Architecture data base. This data base while principally for economic analysis, also includes some technical information. For the Air Force, most of the tactical missile research is conducted at Eglin AFB in Florida.

3. World Missile Data Base

All of the data on world missile systems was obtained from the open literature and contains no subsectional data. Data on a total of 176 missiles was collected and is arranged in tabular form in Appendix A. In addition to the dimensional, weight and derived data mentioned previously, numerical averages are also provided for reference in the tables.

4. Selected U.S. Missile Data Base

This data base contains overall and subsectional data on 32 U.S. missiles collected from sources mentioned previously. Table 1 lists these missiles. The additional technical and performance related data, as well as useful averages, are again provided in tabular form in Appendix A. Several of these missiles are capable of a dual mission role as indicated under the mission column.

TABLE 1: U.S. MISSILE DATA BASE

NAME	DESIG	MISSION	SERVICE
AMRAAM	AIM-120A	AAM	USN/USAF
SPARROW III	AIM-7M	AAM	USN
PHOENIX	AIM-54C	AAM	USN
SIDEWINDER	AIM-9M	AAM	USN/USAF
SHRIKE	AGM-45	ASM	USN/USAF
MAVERICK IR	AGM-65F	ASM	USMC/USN
MAVERICK LASER	AGM-65E	ASM	USMC/USN
PWR GBU-15 IR	AGM-130	ASM	USAF
PWR GBU-15 TV	AGM-130	ASM	USAF
SLAM	AGM-84E	ASM	USN
HELLFIRE	AGM-114A	ASM	USA
HARPOON AIR LNCH	AGM-84	ASM	USN
HARM	AGM-88	ASM	USN/USAF
SM1 MR BLK IV	RIM-66B	SAM/SSM	USN
SM2 MR BLK I	RIM-66C	SAM/SSM	USN
SM2 MR BLK II	RIM-66C	SAM/SSM	USN
SM1 ER BLK V	RIM-67A	SAM	USN
SM2 ER BLK II	RIM-67B	SAM	USN
STINGER	FIM-92A	SAM/AAM	USA/USMC
SEA SPARROW	RIM-7M	SAM	USN
TARTAR	RIM-24B-1	SAM/SSM	USN
CHAPARRAL	MIM-72C	SAM	USA
RAM	RIM-116A	SAM	USN
HAWK	MIM-23	SAM	USA/USMC
PATRIOT	MIM-104	SAM	USA
TASM	BGM-109B	SSM	USN
TLAM-C	BGM-109C	SSM	USN
TOW-2B	BGM-71	SSM/ASM	USA/USMC
LANCE/T-22	MGM-52C	SSM	USA
HARPOON	RGM-84	SSM	USN
PERSHING II	MGM-31A	SSM	USA
MLRS	M-26	SSM	USA

II. METHODOLOGY

A. REGRESSION ANALYSIS AND LEAST SQUARES TECHNIQUE

Regression analysis is a branch of statistics which deals with the investigation of the relationship between two or more variables. With regression analysis, a quantification can be made of the nature and strength of the relationships among one dependent and one or more independent variables. This can be used to build a mathematical model of the relationship which can then be used to predict values for the dependent variable. The first step in regression analysis involving only two variables, i.e., single variable regression analysis, is to build a scatter plot of the observed data. An example of this type of plot is shown in Figure 3.

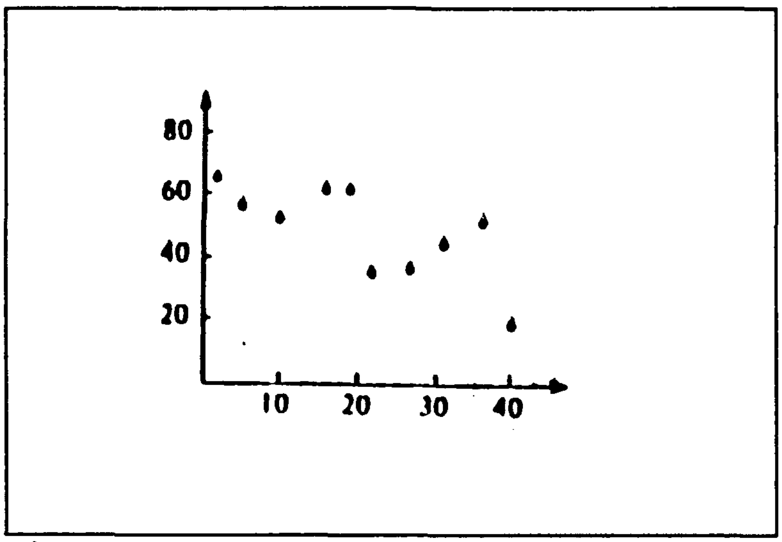

Figure 3: Scatter Plot

While it is clear from the figure that no simple curve will intersect each of the points, it appears reasonable that there is some correlation between the two variables. Assuming that the expected value of y is a linear function of x and that for any fixed value of x, the value of y will differ by some random amount, we can construct the following simple linear regression model:

$$y = b_0 + b_1x + \text{random error}$$

According to this model, the observed values will be distributed about the true regression line in some random manner as depicted in Figure 4. In order to ensure that the model is the best fit, the principle of least squares is used which says basically that a line provides a good fit to the data if the vertical distances, or errors, from the observed points to the line are small. The measure of the goodness of this fit is the sum of the squares of the errors. The line which will have the best fit is therefore, the one having the smallest possible sum of squared errors. (Devore, 1987, pp. 450-459)

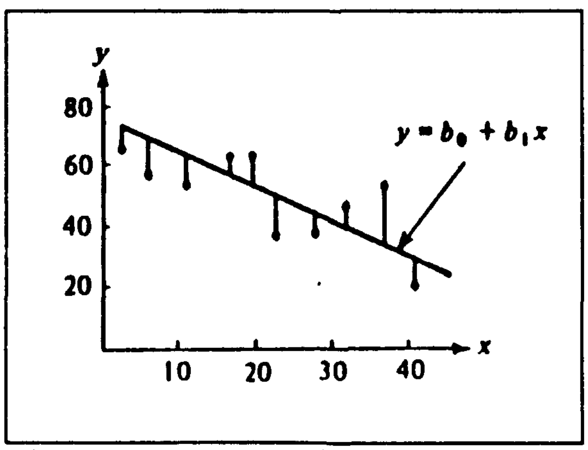

Figure 4: Best Fit Line

With the advent of the high speed digital computer, what in the past had been a laborious task, now became much easier since the minimization of the sum of squared errors is simply a straightforward calculus problem which is readily solved by on a computer. There are a variety of statistical software packages available which offer excellent regression analysis software. After considerable review, the software package selected for this analysis was STATGRAPHICS, a PC based code produced by the Statistical Graphics Corporation. More specifics on the program will be presented in the following sections.

B. SINGLE VARIABLE ANALYSIS

1. Variables

In selecting the variables to be used for single variable analysis, emphasis was placed not only on what choices might conceivably be related, but also on linking variables together which would be of practical usefulness for the engineer or designer. Consequently, as it is assumed that the entering argument will be an approximate knowledge of the maximum length and diameter of the missile based on launcher or carrying restraints, volume is a logical choice as one variable. The weight may or may not be known, although the maximum weight based on these same restraints is oftentimes known. From the standpoint of performance, the desired mission, maximum range and operational speed of the weapon

should be known beforehand. Subsectional dimensions and weights may be known if existing systems, such as an ordnance package or a particular seeker, are to be incorporated into the missile. This is oftentimes an attractive and cost effective option since these systems have already undergone their own design and review process. The goal then is to relate these different performance and physical or geometric parameters together in a logical manner.

The single variable analysis was split into two areas; a total missile analysis and a subsectional analysis. Data for the total missile analysis was obtained from the world missile data base. Data for the subsectional analysis was taken from the U.S. missile data base. Within each of these two areas, the missiles were grouped in an overall, mission area, and range designation category in an attempt to provide groups which were homogeneous enough to yield good relationships.

Within the total missile area, an analysis of weight vs volume was conducted in each of the three categories. Within the overall and mission area categories, weight vs range and volume vs range correlation analyses were conducted.

Within the subsectional analysis area, subsection weight vs subsection volume correlation analyses were carried out for all three subsections in each category. Additionally, in the overall and mission area categories, subsection weight vs range and subsection volume vs range relationships were

explored. For the propulsion subsection, subsection weight and volume were also matched against speed. In an attempt to allow linkage between total and subsectional data, several relationships were investigated using the ratio of the subsectional weight to total weight (W_{sub}/W_t) vs total volume and range.

2. Computer Program

As mentioned previously, the STATGRAPHICS statistical software package was selected to conduct the study. The single variable, or simple, regression procedure fits a model relating one dependent variable to one independent variable through the principle of least squares. It minimizes the sum of squares of the errors, or residuals, for the fitted line. For this study, the following three different models for each relationship were examined:

- Linear $Y = a + bX$
- Multiplicative $Y = aX^b$
- Exponential $Y = \exp(a + bX)$

For the multiplicative and exponential models, logarithmic transformations are applied to the variables with the transformed data then being fitted to a linear model.

In order to determine which model appears to give the best fit, the following parameters calculated by the system were evaluated and compared for the different models for each

run. First, the correlation coefficient which is a measure of the relationship between the predicted and observed values of the dependent variable was examined. The square of this correlation coefficient expressed as a percentage is known as a value called R-squared(R^2). This value is widely used in statistical analysis for measuring how closely the data points match the regression line. The higher the value of R-squared, the better the model. Additionally, the standard error of estimation was evaluated. The standard error of estimation is the square root of the residual mean square. It is the estimated standard deviation of the error and measures the amount of variability in the dependent variable that is not explained by the estimated model.(STATGRAPHICS Reference Manual,1991,pp. S-181 - S-186) Additionally, a plot of the residuals was reviewed for each model. Here, a plot is made of the distance between each data point and the regression line against the independent variable's data points. These residuals can be either positive or negative, and always add up to zero. If a model is a good fit for the data points, the residuals are randomly scattered. Using overall data from the U.S. missile data base for analysis, Figure 5 shows an example of a residuals plot in which the data points are fairly randomly scattered.

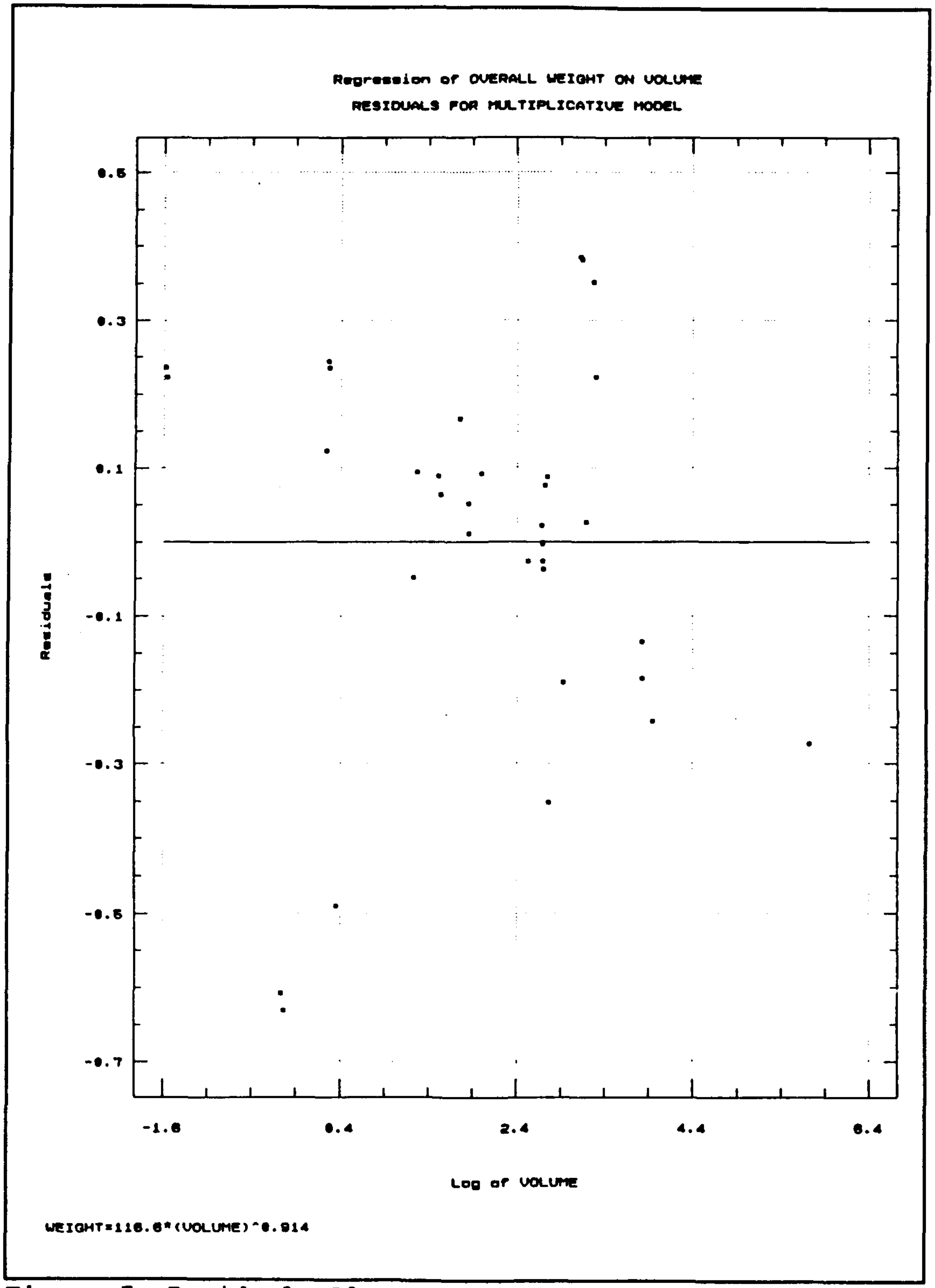

Figure 5: Residuals Plot

In addition to the tools provided for evaluation of the applicability of the model, the system will also provide a plot of the data points and the model as shown in Figure 6. (STATGRAPHICS QuickStart Guide, 1991, pp. 9-18)

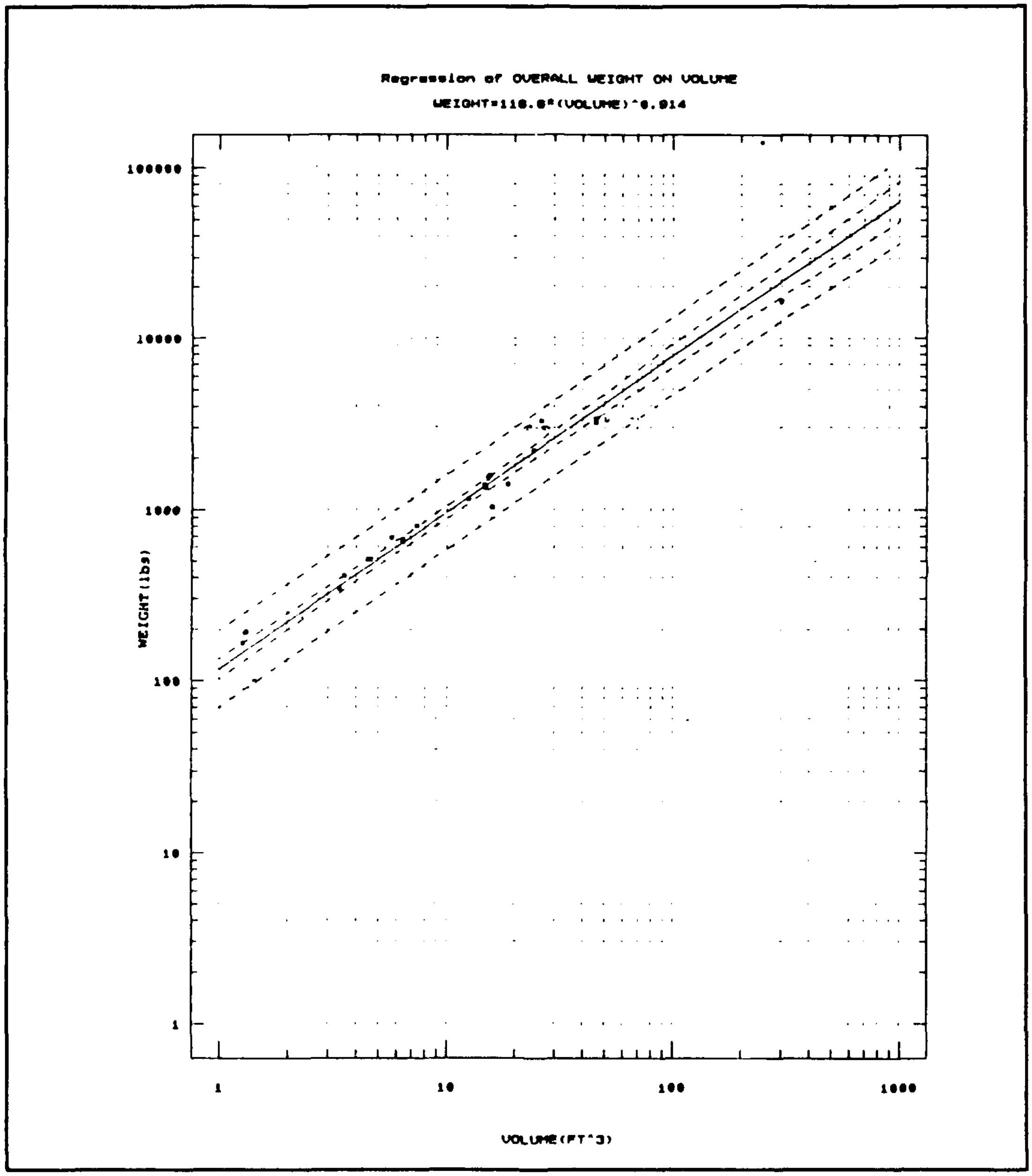

Figure 6: Sample Plot

The plot shows two sets of dashed lines. The inner set marks 95 percent confidence limits for the mean response at any particular value of X. The outer set marks 95 percent prediction limits for the data values predicted by the model. In other words, they represent the range within which 95 percent of the observations will occur for each prediction. While each of these percentages can be varied, a value of 95 percent for each will be used throughout this study.

As mentioned earlier, all three models were considered for each relationship to determine the model with the optimum fit. The best model and its associated value of R-squared will be presented in the body of this work. The plot of the model regression line, data points, confidence and prediction limits will be presented in Appendix B. This will enable the reader to either use the provided equation or to enter the appropriate graph in order to obtain the solution.

C. MULTI-VARIABLE ANALYSIS

1. Variables

a. Subsectional Analysis

The variables for the multi-variable portion of the study were selected using the same criteria as those applied to the single variable portion. The data used was from the U.S. missile data base. The principle aim of this portion of the study was to relate the subsectional weights to the missile's overall physical parameters of length, diameter,

weight, volume, and density as well as to the performance related parameters of mission and range. With a value predicted for the subsection's weight, the designer could then go back into the equations developed in the single variable phase of the study to determine the subsection's approximate volume.

Again, the missiles were grouped in overall, mission type and range designation categories. Computer analysis was then conducted for each of the missile subsections: propulsion, guidance and control, and warhead, utilizing these three groupings. For each relationship analysis, a total of 48 different combinations of the variables were run on the computer. This total is possible since a constant can also be added or deleted in the model. The different combinations are listed in Appendix C.

b. Wing/Fin Analysis

The first assumption for the wing/fin analysis portion was that the weight of a single wing, or fin, would be the dependent variable. The wing or fin to be used was based on the planform with the maximum span as discussed earlier. Note that the weight of a single wing, or fin, not the weight of the total planform is to be used. This choice was based on the fact that once a relationship was found, it could readily be applied to missiles with varying wing/fin configurations such as, monowing, triwing, or cruciform by simply multiplying

the estimated weight by the number of wings in the configuration, in this case; two, three, or four. Due to unavailable data and because the wing weights were sometimes included in the subsection weights, wing/fin data was determined for only 20 of the 32 missiles in the U.S. missile data base. The independent variables selected were: missile weight, aspect ratio, taper ratio, and sweep angle. The missiles were again grouped in overall, mission type, and range designation categories for analysis. For each relationship analysis, a total of 22 computer runs based on various combinations of the data, again with and without a constant in the model, were conducted. These combinations can also be found in Appendix C.

2. Computer Program

The STATGRAPHICS statistical software package was also used for the multi-variable portion of the study. Like the simple regression procedure, the multiple regression procedure uses the least squares technique to estimate the regression model. The system provides the standard error of the coefficients, and the significance level for each independent variable's coefficient in order to enable evaluation of each of the variables in the model. Also, it provides the values for the R-squared and standard error of the estimate parameters discussed previously. An additional statistic provided which is very useful is the mean absolute error(MAE).

The MAE is the average of the absolute values of the residuals. It is the average error which can be expected in a prediction based on the model. For each analysis, the best model, its associated value of R-squared, and the MAE will be recorded.

D. NOMENCLATURE

1. Units

During all phases of analysis and within all equations developed, the following units were used:

- Length(L) FT
- Diameter(D) FT
- Weight(WT or W or Wt) lbs
- Volume(VOL or V) FT^3
- Density(DENS) lbs/FT^3 or PCF
- Range(RNG or R) NM
- Speed(SPD) MACH
- Sweep Angle(SWP) DEG

2. Abbreviations

The following abbreviations in addition to those listed above were used throughout the study for brevity:

- Propulsion Weight PWT or Wprp
- Propulsion Volume PVOL
- Guidance/Control Weight GCWT or Wgc
- Guidance/Control Volume GCVOL

• Warhead Weight	WHWT or Wwh
• Warhead Volume	WHVOL
• Aspect Ratio	AR
• Taper Ratio	TR
• Propulsion	PRP
• Guidance and Control	G/C
• Warhead	WH

III. SINGLE VARIABLE ANALYSIS

A. TOTAL MISSILE ANALYSIS

1. Overall Correlation Analyses

The first relationship analysed was that between total weight and volume for all of the missiles contained in the world missiles data base shown in Tables A-1 through A-4. As an example, this run's process will be covered in detail. The analysis was conducted as discussed earlier by first examining a scatter plot of the weight vs volume data to ensure that there appeared to be some correlation between the two variables. Since this correlation was present, the data was then used as input for the three different models: linear, multiplicative, and exponential to determine which model would give the best fit. Within each model, the value of R-squared and the standard error of estimation was examined and compared. Additionally, the plot of residuals was reviewed to check for randomness. The equations for the three models and their associated values of R-squared are shown below:

- Linear Weight = 1451.3 + 38.1(Volume) R-sq= 94.61
- Mult Weight = 100.9(Volume)$^{0.89}$ R-sq= 97.34
- Exp Weight = exp(6.32 + 0.02(Volume)) R-sq= 28.78

As can be seen, the exponential model provides an extremely poor fit for the data, and for the purposes of the study, a

nominal value of 50 percent was required for R-squared in order to assume an adequate model. Examination of the residual plots for the other two models revealed randomness, and the multiplicative model was selected due to its higher value of R-squared. The graph of the data and regression line is included in Appendix B, Figure B-1. Thus, an estimation may be made by entering the graph with weight or volume, or by using the following equation:

$$\text{Overall Weight} = 100.9(\text{Volume})^{0.89} \quad \text{(EQ 1)}$$

Additional relationships evaluated using all of the missiles included: weight vs range, and volume vs range. The results are shown in Table 1.

TABLE 1: TOTAL MISSILE OVERALL ANALYSES

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
WT VS RANGE	$WT=47.5(RNG)^{0.93}$	87.13	2	B-2
VOL VS RANGE	$VOL=0.46(RNG)^{1.03}$	85.83	3	B-3

Although there is a wide variance in missions, ranges and intended targets for the missiles as a whole, fairly good fits were obtained.

2. Mission Area Correlation Analyses

a. Air-to-Air Missile Category

The data for this category is listed in Table A-1 and consists of 20 missiles. The results are shown in Table 2.

TABLE 2: AAM CATEGORY TOTAL MISSILE ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
WT VS VOL	$WT = 142.2(VOL)^{0.74}$	93.35	4	B-4
WT VS RNG	$WT = 90.4(RNG)^{0.52}$	54.78	5	B-5
VOL VS RNG	$VOL = 0.60(RNG)^{0.66}$	51.00	6	B-6

Note that the relationships linking range to weight and volume are extremely poor.

b. Air-to-Surface Missile Category

The data for this category is listed in Tables A-2A and 2B and consists of 40 missiles. The results are shown in Table 3.

TABLE 3: ASM CATEGORY TOTAL MISSILE ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
WT VS VOL	$WT = 118.5(VOL)^{0.84}$	93.15	7	B-7
WT VS RNG	$WT = 84.8(RNG)^{0.78}$	69.29	8	B-8
VOL VS RNG	$VOL = 0.68(RNG)^{0.92}$	73.35	9	B-9

Note that the fit for the models including range improved, which could be a factor of the greater number of missiles in this data base.

c. Surface-to-Air Missile Category

The data for this category is listed in Tables A-3A and 3B and includes 45 missiles. The results are shown in Table 4.

TABLE 4: SAM CATEGORY TOTAL MISSILE ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
WT VS VOL	$WT= 114.8(VOL)^{0.86}$	97.22	10	B-10
WT VS RNG	$WT= 16.3(RNG)^{1.41}$	88.90	11	B-11
VOL VS RNG	$VOL= 0.12(RNG)^{1.58}$	84.85	12	B-12

d. *Surface-to-Surface Missile Category*

The data for this category is listed in Tables 4A, 4B and 4C and includes 70 missiles. The results are shown in Table 5.

TABLE 5: SSM CATEGORY TOTAL MISSILE ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
WT VS VOL	$WT= 74.9(VOL)^{0.94}$	98.26	13	B-13
WT VS RNG	$WT= 48.9(RNG)^{0.92}$	91.41	14	B-14
VOL VS RNG	$VOL= 0.67(RNG)^{0.97}$	90.71	15	B-15

3. Range Designation Correlation Analyses

The data for the range designation runs is listed in Tables A-5, A-6, and A-7. There were a total of 78 short range missiles, 25 medium range missiles, and 63 long range missiles. As the missiles are already grouped according to range, weight vs volume was the only relationship examined. The results are shown in Table 6.

TABLE 6: RANGE DESIG CATEGORY TOTAL MISSILE ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
SR WT VS VOL	$WT= 99.2(VOL)^{0.93}$	87.25	16	B-16
MR WT VS VOL	$WT= 177.5(VOL)^{0.73}$	85.95	17	B-17
LR WT VS VOL	$WT= 123.9(VOL)^{0.85}$	96.50	18	B-18

As the results show, the grouping by range category also provides models with fairly good fits.

B. PROPULSION SUBSECTION ANALYSIS

1. Overall Correlation Analyses

All of the subsectional analyses were conducted using data from the U.S. missile data base. Overall specifications including range and speed for each missile are listed in Tables A-8 through A-11 which are grouped by mission area. Propulsion subsection specifications are listed in Tables A-12 through A-15, again grouped by mission area.

In addition to attempting to correlate subsection weight, volume, and range it was hypothesized that since the propulsion section is the missile's prime mover, speed might also be a valid variable. Additionally, as the dynamic pressure:

$$q=1/2\rho V^2$$

is a factor in structural design, speed squared was also considered as a variable.

For the overall runs, all of the missiles in the U.S. missile data base were utilized. The results are shown in Table 7.

TABLE 7: OVERALL MSLS PROPULSION SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
PRP WT VS PRP VOL	PWT=94.0+80.9PVOL	99.30	19	B-19
PRP WT VS RANGE	$PWT=31.5(RNG)^{0.81}$	61.84	20	B-20
PRP VOL VS RANGE	$PVOL=0.29(RNG)^{0.83}$	66.14	21	B-21
PRP WT VS SPEED	NO FIT			
PRP VOL VS SPEED	NO FIT			

While a poor fit was obtained for propulsion weight and volume vs range, no model could be constructed with speed as a variable.

2. Mission Area Correlation Analyses

a. Air-to-Air Missile Category

In addition to the relationships examined in the overall analysis, the ratio of the subsection weight to the total weight(Wsub/Wt) was examined versus total volume and range. With this ratio, the subsectional weight could be determined based on the total weight, volume and/or range. The data for this category is listed in Table A-12 and includes 5 missiles. The results are shown in Table 8.

TABLE 8: AAM CATEGORY PROPULSION SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
PRP WT VS PRP VOL	PWT=2.7+112(PVOL)	99.94	22	B-22
PRP WT VS RNG	PWT=34.2+4.1(RNG)	95.02	23	B-23
PRP VOL VS RNG	PVOL=0.28+0.04RNG	95.95	24	B-24
PRP WT VS SPEED	PWT=-122+102.1SPD	73.76	25	B-25
PRP VOL VS SPEED	PVOL=-1.1+0.9SPD	73.31	26	B-26
Wprp/Wt VS VOL	NO FIT			
Wprp/Wt VS RNG	NO FIT			

While relationships involving speed were found, they are applicable only at speeds of greater than approximately Mach 1.2 and should be used cautiously. No relationships involving the weight ratio could be found. Also, the fit for the models including range improved markedly as expected due to a narrower grouping.

b. Air-to-Surface Missile Category

The data for this category is listed in Table A-13 and includes 10 missiles. The results are shown in Table 9.

TABLE 9: ASM CATEGORY PROPULSION SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
PRP WT VS PRP VOL	PWT=56.3+77.2PVOL	88.66	27	B-27
PRP WT VS RNG	$PWT=12.4(RNG)^{1.03}$	80.46	28	B-28
PRP VOL VS RNG	$PVOL=0.19(RNG)^{0.90}$	82.99	29	B-29
PRP WT VS SPEED	NO FIT			
PRP VOL VS SPEED	NO FIT			
Wprp/Wt VS VOL	NO FIT			
Wprp/Wt VS RNG	NO FIT			

c. *Surface-to-Air Missile Category*

The data for this category is listed in Table A-14 and includes 12 missiles. The results are shown in Table 10.

TABLE 10: SAM CATEGORY PROPULSION SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
PRP WT VS PRP VOL	$PWT=119.1(PVOL)^{0.95}$	99.52	30	B-30
PRP WT VS RNG	$PWT=11.7(RNG)^{1.27}$	84.53	31	B-31
PRP VOL VS RNG	$PVOL=0.09(RNG)^{1.33}$	84.12	32	B-32
PRP WT VS SPD	NO FIT			
PRP VOL VS SPD	NO FIT			
Wprp/Wt VS VOL	Wprp/Wt=0.5+0.01PVOL	59.27	33	B-33
Wprp/Wt VS RNG	NO FIT			

d. Surface-to-Surface Missile Category

The data for this category is listed in Table A-15 and includes 11 missiles. The results are shown in Table 11.

TABLE 11: SSM CATEGORY PROPULSION SUBSECTION ANALYSIS

RELATIONSHIPS	EQUATIONS	R-SQ	EQ #	FIG
PRP WT VS PRP VOL	PWT=45.2+80.7(PVOL)	99.50	34	·34
PRP WT VS RNG	$PWT=99.4(RNG)^{0.59}$	55.52	35	B-35
PRP VOL VS RNG	$PVOL=1.08(RNG)^{0.61}$	70.84	36	B-36
PRP WT VS SPD	NO FIT			
PRP VOL VS SPD	NO FIT			
Wprp/Wt VS VOL	$Wprp/Wt=0.36(VOL)^{0.16}$	71.36	37	B-37
Wprp/Wt VS RNG	NO FIT			

3. Range Designation Correlation Analyses

Within each of the range designation categories, two relationships were examined: subsection weight vs subsection volume, and Wsub/Wt vs total volume. Table A-24 lists the missiles within each range category with 11 missiles in the short range category, 7 missiles in the medium range category, and 13 missiles in the long range category. The results are shown in Table 12.

TABLE 12: RANGE DESIG CATEGORY PROP SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
SHORT RANGE				
PRP WT VS PRP VOL	$PWT=95.9(PVOL)^{1.12}$	92.77	38	B-38
Wprp/Wt VS VOL	NO FIT			
MEDIUM RANGE				
PRP WT VS PRP VOL	$PWT=119.4(PVOL)^{0.93}$	98.8	39	B-39
Wprp/Wt VS VOL	Wprp/Wt=0.37+.02VOL	93.00	40	B-40
LONG RANGE				
PRP WT VS PRP VOL	PWT=57.6+80.9PVOL	99.37	41	B-41
Wprp/Wt VS VOL	NO FIT			

As the results show, while good fits were obtained for the subsectional weights vs volumes, it was only within the medium range category that the weight ratio yielded good results.

C. ROCKET PROPULSION ONLY SUBSECTION ANALYSIS

1. Overall Correlation Analyses

Since the physical and performance related characteristics of rocket propulsion systems differ rather markedly from that of air breathing engine systems, an

additional scaled down analysis was conducted after grouping the rocket propulsion missiles together. This necessitated the removal of the following four missiles from the data base: TASM, TLAM-C, HARPOON and SLAM. Since there appeared to be no strong correlation with speed in the earlier analyses, it was deleted as a variable. The results are shown in Table 13.

TABLE 13: OVERALL ROCKET PROP ONLY SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
PRP WT VS PRP VOL	PWT=126.5+81.4(PVOL)	99.61	42	B-42
PRP WT VS RNG	PWT=282.9+14.5(RNG)	94.41	43	B-43
PRP VOL VS RNG	PVOL=1.9+0.18(RNG)	95.28	44	B-44

While good fits were obtained, the models are not applicable for small missiles. This may be due to the fact that there were few extremely small missiles, such as a shoulder fired missile, in the data base.

2. Mission Area Correlation Analyses

The two mission areas affected by the deletion of air breathing engines were the ASM and SSM categories. Within the ASM category, HARPOON and SLAM were deleted and within the SSM

category, HARPOON, TASM, and TLAM-C were deleted. The results for both mission areas are shown in Table 14.

TABLE 14: MSN AREA CATEGORY ROCKET PROP SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
AIR-TO-SURFACE MISSILES				
PRP WT VS PRP VOL	PWT=4.5+107.8(PVOL)	98.62	45	B-45
PRP WT VS RNG	$PWT=7.67(RNG)^{1.28}$	85.29	46	B-46
PRP VOL VS RNG	$PVOL=0.17(RNG)^{0.95}$	76.53	47	B-47
SURFACE-TO-SURFACE MISSILES				
PRP WT VS PRP VOL	PWT=154.3+80.6(PVOL)	99.82	48	B-48
PRP WT VS RNG	PWT=632.8+14.1(RNG)	99.18	49	B-49
PRP VOL VS RNG	PVOL=5.9+0.18(RNG)	98.98	50	B-50

As the results indicate, for the mission area categories, the fit for the models improved dramatically. Thus, if it is known that the propulsion system to be used is a rocket type, these are the equations of choice.

D. GUIDANCE AND CONTROL SUBSECTION ANALYSIS

1. Overall Correlation Analyses

The overall runs for the guidance and control subsection were conducted similarly to those for the propulsion subsection although, as there seemed to be no correlation between speed and the physical characteristics associated with guidance and control, speed was not considered as a variable. The data on the guidance and control subsections are listed in Tables A-16 through A-19. The results for the overall correlation analyses are shown in Table 15.

TABLE 15: OVERALL G/C SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
G/C WT VS G/C VOL	$GCWT=75.9(GCVOL)^{0.62}$	83.04	51	B-51
G/C WT VS G/C RNG	NO FIT			
G/C VOL VS RNG	$GCVOL=0.2(RNG)^{0.80}$	58.64	52	B-52

Perhaps due to the fact that this is such a broad grouping, where a model was obtained, the fit was relatively poor.

2. Mission Area Correlation Analyses

a. Air-to-Air Missile Category

The mission area runs for the guidance and control subsection were conducted similarly to those for the propulsion subsection. Again, speed was not considered.

The data for this category is listed in Table A-16 and includes 5 missiles. The results are shown in Table 16.

TABLE 16: AAM CATEGORY G/C SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
G/C WT VS G/C VOL	$GCWT=83.9(GCVOL)^{0.63}$	98.21	53	B-53
G/C WT VS RNG	$GCWT=12.9+2.8(RNG)$	98.74	54	B-54
G/C VOL VS RNG	$GCVOL=20.9(RNG)^{1.01}$	81.93	55	B-55
Wgc/Wt VS VOL	NO FIT			
Wgc/Wt VS RNG	NO FIT			

As indicated by the results, the more specific grouping by mission area may have been responsible for the much better fit for the relations involving range.

b. Air-to-Surface Missile Category

The data for this category is listed in Table A-17 and contains 10 missiles. The results are shown in Table 17.

TABLE 17: ASM CATEGORY G/C SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
G/C WT VS G/C VOL	$GCWT= 74.9(GCVOL)^{0.81}$	89.65	56	B-56
G/C WT VS RNG	NO FIT			
G/C VOL VS RNG	$GCVOL= 0.18(RNG)^{0.93}$	57.79	57	B-57
Wgc/Wt VS VOL	NO FIT			
Wgc/Wt VS RNG	NO FIT			

c. *Surface-to-Air Missile Category*

The data for this category are listed in Table A-18 and includes 12 missiles. The results are shown in Table 18.

TABLE 18: SAM CATEGORY G/C SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
G/C WT VS G/C VOL	$GCWT= 74.6(GCVOL)^{0.62}$	96.74	58	B-58
G/C WT VS RNG	$GCWT= 9.4(RNG)^{0.87}$	82.83	59	B-59
G/C VOL VS RNG	$GCVOL=0.0038(RNG)^{1.38}$	81.61	60	B-60
Wgc/Wt VS VOL	Wgc/Wt=exp(-1.3-0.04VOL)	60.74	61	B-61
Wgc/Wt VS RNG	Wgc/Wt=exp(-1.38-0.017RNG)	50.14	62	B-62

As indicated, a model was found for each relationship although the measures of fit for the models including the weight ratios are poor. Note also, that for the weight ratios the models are exponential.

d. *Surface-to-Surface Category*

The data for this category are listed in Table A-19 and contain 11 missiles. The results are shown in Table 19.

TABLE 19: SSM CATEGORY G/C SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
G/C WT VS G/C VOL	GCWT=86.7+18.9(GCVOL)	82.48	63	B-63
G/C WT VS RNG	NO FIT			
G/C VOL VS RNG	NO FIT			
Wgc/Wt VS VOL	NO FIT			
Wgc/Wt VS RNG	NO FIT			

As shown, there were no relationships found with the exception of subsection weight vs volume which had a poor fit. The cause for this may lie in the fact while the missiles in the data base are all surface to surface, their modes of operation, launch platforms, and intended targets are extremely diverse. Although it would be attractive to further classify the missiles based on the foregoing considerations, there would not be enough data in any one category to be statistically significant.

3. Range Designation Correlation Analyses

Again, the range designation correlation analyses for the guidance and control subsection were conducted exactly the same way as those for the propulsion subsection with the same missiles in each range designation category. Subsection weight vs volume and Wgc/Wt vs total volume were the relationships examined. The results are shown in Table 20.

TABLE 20: RANGE DESIG CATEGORY G/C SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
SHORT RANGE				
G/C WT VS G/C VOL	$GCWT= 78(GCVOL)^{0.69}$	93.28	64	B-64
Wgc/Wt VS VOL	NO FIT			
MEDIUM RANGE				
G/C WT VS G/C VOL	$GCWT=108.3(GCVOL)^{0.42}$	75.56	65	B-65
Wgc/Wt VS VOL	$Wgc/Wt=\exp(-0.89-0.06VOL)$	87.83	66	B-66
LONG RANGE				
G/C WT VS G/C VOL	$GCWT=104.6+18.2(GCVOL)$	81.64	67	B-67
Wgc/Wt VS VOL	NO FIT			

For the range designation correlation analyses, the short range missiles model for subsection weight vs volume had a much better fit than those for the medium or long range missiles. Interestingly, as in the propulsion subsection

analysis, the only category which showed a relationship between the weight ratio and volume was the medium range category.

4. Guidance and Control Technology Factor

One area of concern with the guidance and control subsection analysis was the fact that the missiles considered were designed utilizing technologies from the 1950s through the 1990s. A considerable amount of evolution has taken place during this time span as electronics have progressed from heavy vacuum tubes with high power and heat dissipation requirements to printed circuits and micro-electronics.(Pierson, 1987,p. 9) With this in mind, an attempt to account for these technological differences was undertaken by using the concept of a technology factor.

A technology factor is a factor that allows the combination of data from different technology eras in order to derive an estimation equation which enables the prediction of future design parameters. An application of this technique found in the Society of Allied Weight Engineers(SAWE) Paper No. 1760, *Sizing Missile Guidance Systems*(Pierson,1987), was used as guidance. The paper applied this concept to the formulation of equations linking autopilot weight with range.

The first step was to empirically derive the equation involving the desired relationship using the available data. This was completed and documented in the previous section.

Next, a trend is established between the desired variable, in this case weight or volume, and the technology or design era. Once this trend is quantified through regression analysis, the equation linking the desired variable to a year of significance is combined with the previously developed equation for the variable in a fairly straightforward manner.

Although not exactly the design era, the year in which production started was used as the standard measure for each missile to ensure commonality. Utilizing the data listed in Tables A-16 through A-19, an attempt was made to link the guidance and control subsection weight and volume to the production start year utilizing the same categories used previously: overall, mission type, and range designation, with no success. That is there was no clear trend such as weight decreasing with increasing technology found. Without this relationship, a technology factor cannot be developed.

The fact that a relationship could not be found is not too surprising since the breakdown by subsection is not very specific. In the case of a component such as an autopilot, the degree of specificity is such that one would expect a trend. While it was anticipated that development of a technology factor at this level of analysis might not be possible, it was necessary to verify the assumption. Additionally, it highlights the fact that care should be exercised when using the equations as they were developed from data spanning multiple technology eras.

E. WARHEAD SUBSECTION ANALYSIS

1. Overall Correlation Analysis

Unlike the propulsion and guidance and control subsections, there appeared to be no linkage between the warhead subsection size and range. Consequently, the only relationship examined overall was that between warhead weight and volume, keeping in mind that the warhead subsection encompasses the payload, fuze, and the safety and arming device. The data for this analysis was taken from Tables A-20 through A-23. The result is shown in Table 21.

TABLE 21: OVERALL WARHEAD SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
W/H WT VS W/H VOL	$WHWT=119.3(WHVOL)^{0.93}$	93.95	68	B-68

2. Mission Area Correlation Analyses

In addition to the subsection weight vs volume relationship, within the mission area category runs, the Wwh/Wt vs total volume relationship was examined. The data for these runs was taken from Tables A-20 through A-23. The results are shown in Table 22.

TABLE 22: MISSION AREA CATEGORIES W/H SUBSECTION ANALYSIS

RELATIONSHIP	EQUATION	R-SQ	EQ #	FIG
AIR-TO-AIR MISSILES				
W/H WT VS W/H VOL	$WHWT=103.9(WHVOL)^{0.78}$	95.28	69	B-69
Wwh/Wt VS VOL	$Wwh/Wt=0.13(VOL)^{0.098}$	76.51	70	B-70
AIR-TO-SURFACE MISSILES				
W/H WT VS W/H VOL	$WHWT=117.1(WHVOL)^{1.24}$	97.67	71	B-71
Wwh/Wt VS VOL	Wwh/Wt=0.27+0.014(VOL)	61.22	72	B-72
SURFACE-TO-AIR MISSILES				
W/H WT VS W/H VOL	$WHWT=109.5(WHVOL)^{0.83}$	99.15	73	B-73
Wwh/Wt VS VOL	Wwh/Wt=0.17-0.0029VOL	50.10	74	B-74
SURFACE-TO-SURFACE MISSILES				
W/H WT VS W/H VOL	$WHWT=92.3(WHVOL)^{1.03}$	92.29	75	B-75
Wwh/Wt VS VOL	NO FIT			

As expected, strong fits were obtained for weight vs volume. Although the measures of fit are not that strong, the majority of the categories also produced models for the weight ratio vs volume.

IV. MULTI-VARIABLE SUBSECTION ANALYSIS

A. PROPULSION SUBSECTION ANALYSIS

1. Overall Correlation Analysis

As discussed previously, the multi-variable phase of the analysis used the same subsectional data from the U.S. missile data base as that used for the single variable phase. The aim was to relate the subsection's weight to the missile's overall physical parameters of length(L), diameter(D), weight(W), volume(V), and density(DENS) as well as to the performance related variable of range(R). Once the subsectional weight is known, the subsectional volume can be determined by use of the equations developed in the preceding chapter. For each of the analyses, a total of 48 different combinations of the variables, including a model constant, were analysed on the computer. The listing for these combinations is included in Appendix C. For each correlation analysis, in addition to the model's equation, the values of R-squared and the mean absolute error(MAE), described earlier, will be displayed. The data for the overall correlation analyses was compiled from Tables A-12 through A-15 and includes 32 missiles. The result is shown in Table 23.

TABLE 23: OVERALL PROPULSION SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
PWT= 821.7+42.6(L)+0.41(W)-1135.5(D)+31.6(V)-0.33(R)-4.8(DENS)	98.70	171.20	76

As the MAE shows, since an estimation would have an average error of 171.20 pounds, this would certainly not be the equation of choice. This high MAE is probably due to the lack of specificity in the grouping.

2. Mission Area Correlation Analyses

The data for the mission area correlation analyses were also taken from Tables A-12 through A-15. It consists of 5 AAMs, 10 ASMs, 12 SAMs, and 11 SSMs. The results are shown in Table 24.

3. Range Designation Correlation Analyses

The missiles in each of the range designation categories are listed in Table A-24 and includes 11 short range missiles, 7 medium range missiles, and 13 long range missiles. The results are shown in Table 25.

TABLE 24: MSN AREA CATEGORY PROPULSION SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
AIR-TO-AIR MISSILES			
PWT=-284.9+633.6(D)-0.105(W)+0.949(DENS)	100	0.01	77
AIR-TO-SURFACE MISSILES			
PWT=-160.9+17.6(L)+175.6(D)+0.086(W)-6.8(V)+3.4(R)	99.80	5.60	78
SURFACE-TO-AIR MISSILES			
PWT=8.3(L)-288.9(D)+1.2(W)-26.7(V)-6.37(R)	99.80	40.90	79
SURFACE-TO-SURFACE MISSILES			
PWT=-1973.5-256.1(L)-0.3(R)+0.1(W)+2459.4(D)+26.7(DENS)	99.90	61.20	80

As expected, grouping the missiles by mission area resulted in models with much better fits than the model derived overall. Additionally, the MAE decreased from that observed overall. The increase in the value for the MAE for successive mission areas may be accounted for in the fact that, on the whole, SAMs are bigger than AAMs etc.

TABLE 25: RNG DESIG CATEGORY PROPULSION SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
SHORT RANGE			
$PWT=108.3(V)+2.1(L)^2 -0.7(W)-171.5(D)$	98.40	37.40	81
MEDIUM RANGE			
$PWT=1548.0-43.7(L)-1253.9(D) +1.4(W)-6.0(DENS)$	99.90	13.98	82
LONG RANGE			
$PWT=1480.8-1476.9(D)+1.1(W) -0.3(R)-6.4(DENS)$	99.87	97.60	83

B. GUIDANCE AND CONTROL SUBSECTION ANALYSIS

1. Overall Correlation Analysis

The data for the overall run was compiled from tables A-16 through A-19. The result is shown in Table 26.

TABLE 26: OVERALL G/C SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
$GCWT=-6.9(V)+176.7(D) +0.2(W)-7.9(L)$	90.00	63.76	84

2. Mission Area Correlation Analyses

The data for these runs are listed in Tables A-16 through A-19 and include 5 AAMs, 10 ASMs, 12 SAMs, and 11 SSMs. The results are shown in Table 27.

TABLE 27: MSN AREA CATEGORY G/C SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
AIR-TO-AIR MISSILES			
GCWT=117.6(D)+1.6(R)-0.14(DENS)	99.80	6.28	85
AIR-TO-SURFACE MISSILES			
GCWT=0.2(W)+0.7$(L)^2$-2.3(R)	99.40	19.06	86
SURFACE-TO-AIR MISSILES			
GCWT=265.6(D)-2.0(V)-0.4(DENS)	97.80	20.8	87
SURFACE-TO-SURFACE MISSILES			
GCWT=1099.9+219.2(L)-0.6(W) -2657.9(D)+34.2(V)+0.2(R)-9.3(DENS)	97.70	23.0	88

3. Range Designation Correlation Analyses

The missiles used for these analyses are listed in Table A-24 and include 11 short range, 7 medium range, and 13 long range missiles. The results are shown in Table 28.

TABLE 28: RNG DESIG CATEGORY G/C SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
SHORT RANGE			
$GCWT=29.0(D)+0.2(W)-0.3(L)^2 -0.8(V)$	99.00	15.98	89
MEDIUM RANGE			
$GCWT=38.9(L)+910.9(D)-77.3(V) +0.3(W)-7.4(DENS)$	98.00	19.90	90
LONG RANGE			
$GCWT=1356.8-637.9(D)+0.1(W) +0.2(R)-6.5(DENS)$	88.80	53.09	91

Again, good fits and reasonable MAEs were obtained using the range designation categories.

C. WARHEAD SUBSECTION ANALYSIS

1. Overall Correlation Analysis

The data for the overall run was compiled from Tables A-20 through A-23. The result is shown in Table 29.

TABLE 29: OVERALL W/H SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
WHWT=-46.7(L)+564.5(D)+0.7(W) -36.4(V)+0.3(R)	81.70	194.1	92

2. Mission Area Correlation Analyses

The data for these analyses are listed in Tables A-20 through A-23 and include 5 AAMs, 10 ASMs, 12 SAMs, and 11 SSMs. The results are shown in Table 30.

TABLE 30: MSN AREA CATEGORY W/H SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
AIR-TO-AIR MISSILES			
WHWT=0.1(DENS)-0.2(R)+0.2(W)-2.4(L)	99.90	1.15	93
AIR-TO-SURFACE MISSILES			
WHWT=157.4-587.5(D)+65.7(V)+0.4(W) -78.4(L)+0.96(R)+6.5(DENS)	99.90	20.40	94
SURFACE-TO-AIR MISSILES			
WHWT=-4.61(L)+121.8(D)-0.04(W) +8.7(V)+1.4(R)	98.97	11.60	95
SURFACE-TO-SURFACE MISSILES			
WHWT=49.2(V)+145.9(L)-1.2(W)+0.4(R) -9.9(DENS)	93.10	133.20	96

3. Range Designation Correlation Analyses

The missiles used for these analyses are listed in Table A-24 and include 11 short range, 7 medium range, and 13 long range missiles. The results are shown in Table 31.

TABLE 31: RNG DESIG CATEGORY W/H SUBSECTION ANALYSIS

EQUATION	R-SQ	MAE	EQ #
SHORT RANGE			
WHWT=-25.4(L)+336.8(D) +1.7(W)-148.6(V)	99.40	33.60	97
MEDIUM RANGE			
WHWT=-582.1+1.2$(L)^2$ +1013.2(D)-0.1(W)-32.7(V)	98.90	3.54	98
LONG RANGE			
WHWT=-6363.2+57.8(V) -1.6(W)+0.3(R)+112.2(L) +3136.1(D)+31.1(DENS)	85.60	107.24	99

V. MULTI-VARIABLE WING/FIN ANALYSIS

A. OVERALL CORRELATION ANALYSIS

The wing/fin analysis was conducted as discussed previously and in a similar fashion to the subsectional analysis. In review, the goal was to relate the weight of a single wing or fin to some combination of the overall missile weight(W), aspect ratio(AR), taper ratio(TR), and sweep angle(SWP). For each relationship analysis, a total of 22 combinations of the variables, including a model constant, were run on the computer. The combinations of the variables are listed in Appendix C. Data was available on 20 of the missiles in the U.S. missile data base. The data for the overall run is shown in Tables A-25 through A-28. The result is shown in Table 32.

TABLE 32: OVERALL WING/FIN ANALYSIS

EQUATION	R-SQ	MAE	EQ #
WINGWT=0.00068(W)-7.5(TR) +0.2(SWP)+0.4(AR)	84.70	2.89	100

B. MISSION AREA CORRELATION ANALYSES

The data for these runs are listed in Tables A-25 through A-28 and include 4 AAMs, 4 ASMs, 9 SAMs, and 7 SSMs. The results are shown in Table 33.

TABLE 33: MSN AREA CATEGORY WING/FIN ANALYSIS

EQUATION	R-SQ	MAE	EQ #
AIR-TO-AIR MISSILES			
WINGWT=31.3+0.04(W)-0.8(SWP)	96.40	0.54	101
AIR-TO-SURFACE MISSILES			
WINGWT=86.7-7.7(AR)-1.4(SWP)	100	0	102
SURFACE-TO-AIR MISSILES			
WINGWT=19.0-5.8(AR)+0.4(SWP) +0.0009(W)-66.6(TR)	96.30	0.93	103
SURFACE-TO-SURFACE MISSILES			
WINGWT=10.2-1.2(AR)+0.1(SWP) -12.4(TR)+0.0005(W)	99.30	0.17	104

As shown, the relationships found exhibit excellent fits as well as very small MAEs.

C. RANGE DESIGNATION CORRELATION ANALYSES

The missiles used for these analyses are listed in Table A-29 and include 7 short range, 7 medium range, and 9 long range missiles. The results are shown in Table 34.

TABLE 34: RNG DESIG CATEGORY WING/FIN ANALYSIS

EQUATION	R-SQ	MAE	EQ #
SHORT RANGE			
WINGWT=5.4+0.005(W) -0.2(SWP)+11.1(TR)	98.30	0.24	105
MEDIUM RANGE			
WINGWT=-89.8+0.03(W) +0.99(SWP)+13.0(AR)	99.80	0.27	106
LONG RANGE			
WINGWT=1.3(AR)+0.1(SWP)+0.0006(W)	98.90	1.03	107

As indicated, the grouping by range designation also yielded excellent results.

VI. DESIGN EXAMPLE

The following example will serve to illustrate one possible application of the equations developed. A new air-to-air missile is being considered for use with the F/A-18 series aircraft. The following preliminary requirements are specified:

- Range 35 NM
- Speed Mach 3.5
- Max Length 13 FT
- Max Diameter 0.65 FT

A first approximation of the missile's overall weight and subsectional weights and lengths is desired for review.

The first step is to calculate the missile's overall volume based on the above length and diameter, utilizing the formula:

$$VOLUME = (\Pi \times D^2 \times LENGTH)/4$$

The calculated total volume is equal to 4.31 FT^3. In order to get an initial estimation for the weight, EQ 4 from the AAM category total missile analysis is selected for use:

$$\text{WEIGHT} = 142.2(\text{VOL})^{0.74}$$

$$\text{WEIGHT} = 419 \text{ lbs}$$

This initial estimate can be checked with the equation developed for the medium range category, EQ 17:

$$\text{WEIGHT} = 177.5(\text{VOL})^{0.73}$$

$$\text{WEIGHT} = 515 \text{ lbs}$$

Since these values differ, the fit for each is compared and EQ 4 is selected based on a much higher value of R-squared. Therefore, the initial estimation for total weight is equal to 419 lbs. With the weight and volume known, the total missile density can be calculated with the equation:

$$\text{DENSITY} = \text{WEIGHT}/\text{VOLUME}$$

$$\text{DENSITY} = 97.22 \text{ lbs}/\text{FT}^3$$

The next step is to enter the equations developed for the subsection weights with the data that has been given, derived, and estimated. First, the propulsion subsection weight can be estimated with EQ 77, developed in the mission area category:

$$\text{PWT} = -284.9+633.6(\text{D})-0.105(\text{W})+0.949(\text{DENS})$$

$$\text{PWT} = 175 \text{ lbs}$$

This value is checked with EQ 82 developed in the range designation category:

$$\text{PWT} = 1548.0-43.7(\text{L})-1253.9(\text{D})+1.4(\text{W})-6.0(\text{DENS})$$

$$\text{PWT} = 168 \text{ lbs}$$

Both equations are in agreement. Since EQ 77 had a better fit and smaller MAE, the value of 175 lbs will be used for the propulsion subsection weight. With the subsection weight now

known, an estimation of the subsection's volume can be made with EQ 22 developed in the AAM category:

$$PWT = 2.7+112(PVOL)$$

$$PVOL = 1.54\ FT^3$$

Again using an equation developed in the range designation category, this value is checked with EQ 39:

$$PWT = 119.4(PVOL)^{0.93}$$

$$PVOL = 1.51\ FT^3$$

These values are also in close accordance and after comparing each equation's measure of fit and MAE, the value of 1.54 FT^3 will be used. With the subsection volume known, the subsection's length can be determined utilizing the formula for volume shown earlier and the assumption that the subsection diameter is equal to the missile diameter. Remember that with the modular design of today's missiles, this assumption is almost always valid. Therefore, the propulsion subsection length is estimated to be:

$$PLEN = 4.64\ FT$$

Second, the guidance and control subsection's weight and size will be estimated in the same manner. As before, an estimation will be obtained first with the equation developed in the mission area category analysis and compared to the value obtained by using the equation developed in the range designation category analysis. The value given by the

equation with the better fit and lower MAE will be used. An estimation for the subsection's weight is obtained from EQ 85:

$$GCWT = 117.6(D)+1.6(R)-0.14(DENS)$$

$$GCWT = 119 \text{ lbs}$$

This value is compared to that obtained from EQ 90:

$$GCWT = 38.9(L)+910.9(D)-77.3(V)+0.3(W)-7.4(DENS)$$

$$GCWT = 170 \text{ lbs}$$

Since their is some variance, an additional estimation can be computed with EQ 66:

$$Wgc/Wt = \exp(-0.89-0.06(VOL))$$

$$Wgc/Wt = 0.317$$

$$GCWT = 132 \text{ lbs}$$

This seems to validate the value obtained with EQ 85 which also had a better fit and lower MAE. Thus, a value of 119 lbs will be used as the estimation for the guidance and control subsection weight. Continuing with subsection volume and length, EQ 53 gives:

$$GCWT = 83.9(GCVOL)^{0.63}$$

$$GCVOL = 1.74 \text{ FT}^3$$

$$GCLEN = 5.25 \text{ FT}$$

Checking with EQ 65 gives:

$$GCWT = 108.3(GCVOL)^{0.42}$$

$$GCVOL = 1.25 \text{ FT}^3$$

$$GCLEN = 3.77 \text{ FT}$$

This is quite a bit different, but could be due to the fact that R-squared for EQ 65 was only 75.56. The values obtained through EQ 53 will be used.

Third, the warhead subsection's weight and size will be estimated. For subsection weight, EQ 93 gives:

$$WHWT = 0.1(DENS)-0.2(R)+0.2(W)-2.4(L)$$

$$WHWT = 55 \text{ lbs}$$

This value is compared with the value obtained by EQ 98:

$$WHWT = -582.1+1.2(L)^2+1013.2(D)-0.1(W)-32.7(V)$$

$$WHWT = 96 \text{ lbs}$$

Again, variance leads to another check by using EQ 70:

$$Wwh/Wt = 0.13(VOL)^{0.098}$$

$$Wwh/Wt = 0.15$$

$$WHWT = 63 \text{ lbs}$$

Therefore, a value of 55 lbs will be used for the warhead's weight. Continuing with subsection volume and length, EQ 69 gives:

$$WHWT = 103.9(WHVOL)^{0.78}$$

$$WHVOL = 0.44 \text{ FT}^3$$

$$WHLEN = 1.33 \text{ FT}$$

Last, an estimation of wing/fin weight will be conducted. For the purposes of this example, it will be assumed that a cruciform wing and tail fin configuration has been chosen and that the surface with the maximum span has the following dimensions:

- Taper Ratio(TR) 0.28
- Aspect Ratio(AR) 2.25
- Sweep Angle(SWP) 55 DEG

For an estimation of a single wing or fin's weight, EQ 101 gives:

$$WINGWT = 31.3+0.04(W)-0.8(SWP)$$

$$WINGWT = 4.06 \text{ lbs}$$

This value is checked with EQ 106:

$$WINGWT = -89.8+0.03(W)+0.99(SWP)+13.0(AR)$$

$$WINGWT = 6.47 \text{ lbs}$$

Since EQ 106 has a better fit and lower MAE, a value of 6.47 lbs will be used as an estimation for a single wing or fin's weight. The total can be approximated by multiplying this figure by the total number of wings and fins, in this case, 8. Thus, the total wing/fin weight estimation is equal to 52 lbs.

In summary, the following synopsis of the weight and size estimations for the missile are provided:

- Propulsion Subsection Weight= 175 lbs Length= 4.64 FT
- Guid/Control Subsection Weight= 119 lbs Length= 5.25 FT
- Warhead Subsection Weight= 55 lbs Length= 1.33 FT
- Wing/Fins Weight= 52 lbs
- Total Missile Weight= 401 lbs Length=11.22 FT

As this summary shows, the final weight and length based on the sum of the estimated subsection values are very close to the entering arguments of 419 lbs and 13 FT. Additionally, comparison of these subsection and overall weights and lengths shows good agreement with existing systems.

VII. SUMMARY

In summary, this study has addressed the problem of weight and size estimation for missiles in a manner that has remained in the open literature. Additionally, it presents a body of equations which provide quick and comparatively easy solutions for computation of overall and subsectional weights and sizes based on a broad range of physical and performance related input parameters.

While a detailed review of each relationship examined is not possible here, a few observations will be made. First, a few comments regarding the single variable portion of the analysis. Excellent results were obtained for the majority of the weight vs volume relationships examined. Although the fits were not as strong, in most cases good results were also obtained for the weight and volume vs range relationships. Speed was not an effective variable in any of the relationships. Nor could any relationships between the Wsub/Wt ratio and range be found. Although the Wsub/Wt ratio vs total volume was found to be valid for only a few categories, as the design example demonstrated, it proved useful when applicable. For the multi-variable portion, strong relationships were found for both subsections and wing/fins.

As exhibited in the design example, the presentation of the estimation equations within their category groupings and with their respective measures of fit and error make it simple to rapidly obtain and compare estimates. It should be stressed that these estimations should only be used as initial approximations. Also, care must be exercised as the configuration evolution progresses that equations based on present and past technology are not applied to anything which is radically different in terms of technology.

APPENDIX A - DATA

A. WORLD MISSILES DATA BASE

1. Mission Area Categories

TABLE A-1: WORLD AIR-TO-AIR MISSILES

NAME	RNG	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
SKYFLASH	27	UK	425	4.62	92.03
PHOENIX	100	USA	1030	15.95	64.56
AMRAAM	35	USA	339	3.39	99.92
SPARROW III	50	USA	508	4.54	111.87
ANAB	11	USSR	605	8.52	70.97
STINGER	3	USA	35	0.21	168.49
SUPER 530	22	FRANCE	550	7.38	74.53
MAA-1	5	BRAZIL	198	1.81	109.61
SIDEWINDER	2	USA	189	1.30	145.13
MAGIC	5	FRANCE	200	1.77	113.18
R.530	9.7	FRANCE	423	6.87	61.57
KUKRI	2	SAFRICA	161	1.21	133.46
SHAFRIR	2.7	ISRAEL	205	1.61	127.33
APEX	19	USSR	704	3.39	207.13
APHID	4	USSR	121	0.89	135.62
PYTHON	8	ISRAEL	264	1.92	137.20
ASH	9	USSR	860	13.35	64.41
PL-5B	8.6	CHINA	187	1.19	156.64
ASPIDE	40	ITALY	485	4.66	104.16
ATOLL	3.5	USSR	154	1.16	133.21
AVERAGE			382	4.29	115.55

TABLE A-2A: WORLD AIR-TO-SURFACE MISSILES(PARTIAL)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
MARTIN PESCADOR	4	ARGENTINA	308	3.69	83.37
MARTEL	32	FRANCE	1170	18.32	63.88
HELLFIRE	4	USA	99	1.43	69.39
PWR GBU-15TV	16	USA	2980	22.76	130.95
HARPOON AIR LAUNCH	62	USA	1145	12.54	91.27
HARM	43	USA	795	7.39	107.52
SLAM	50	USA	1332	14.79	90.07
MARTE	10.8	ITALY	726	5.66	128.33
ALCM	1348	USA	2816	65.03	43.30
KITCHEN	119	USSR	13200	262.24	50.33
KIPPER	162	USSR	9240	204.76	45.12
KINGFISH	300	USSR	10580	224.18	47.19
KERRY	6	USSR	2640	9.03	292.30
KELT	150	USSR	6600	213.24	30.95
SAAB 04E	16	SWEDEN	1350	29.35	45.99
KORMORAN	20	FRG	1320	13.68	96.46
SRAM	100	USA	2222	26.51	83.83
SEA SKUA	13.5	UK	319	4.12	77.39
SEA EAGLE	53	UK	1320	18.32	72.07
SWATTER	1.5	USSR	60	0.65	92.60
SAGGER AS	1	USSR	25	0.35	71.05

TABLE A-2B: WORLD AIR-TO-SURFACE MISSILES(CONT)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENSITY
	NM		lbs	FT^3	lbs/FT^3
SAAB 05A	4.85	SWEDEN	671	9.27	72.40
KANGAROO	350	USSR	24200	1429.04	16.93
TOW 2B	2	USA	50	0.77	64.96
SHRIKE	9	USA	409	3.56	114.78
MAVERICK IR	14	USA	669	6.39	104.64
MAVERICK LASER	14	USA	642	6.39	100.42
PENGUIN MK2 MOD7	27	NORWAY	763	6.62	115.33
PENGUIN MK3	16	NORWAY	748	6.23	119.98
PWR GBU-15(IR)	16	USA	3022	23.20	130.22
RBS-15	52	SWEDEN	1316	28.75	45.77
SKIPPER II	20	USA	1280	28.35	45.15
ASM-1	65	JAPAN	1342	12.45	107.80
ARMAT	65	FRANCE	1210	16.86	71.78
GABRIEL II AS	32	ISRAEL	1320	11.97	110.24
ASMP	135	FRANCE	1848	19.90	92.84
EXOCET AM-39	33	FRANCE	1434	14.63	97.98
AS.30	6	FRANCE	1144	12.16	94.05
AS.15TT	8	FRANCE	220	2.12	103.75
HOT AS	1	FRANCE	52	0.53	97.96
AVERAGE			2536	69.85	88.13

TABLE A-3A: WORLD SURFACE-TO-AIR MISSILES (PARTIAL)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
RAY RIDER	2.7	SWEDEN	52	0.54	96.98
RAPIER	3.23	UK	94	0.92	102.14
JAVELIN	2	UK	34	0.22	156.49
ROLAND	4.5	FRANCE	149	1.55	96.06
PATRIOT	62	USA	2200	24.17	91.01
HAWK	22	USA	1398	18.67	74.92
RAM	5	USA	164	1.27	128.67
SA-N-4	8	USSR	418	4.04	103.45
CHAPPARRAL	3	USA	190	1.32	144.36
SM2 MR BLKI	40	USA	1385	14.64	94.59
BLOWPIPE	2	UK	32	0.22	148.16
SEAWOLF	5	UK	176	1.84	95.76
ASPIDE	9.7	ITALY	485	4.66	104.15
SEA DART	43	UK	1210	22.32	54.21
SEACAT	3	UK	150	1.39	108.27
CROTALE	4	FRANCE	178	1.88	94.43
BARAK	6	ISRAEL	189	2.04	92.84
SA-N-6	30	USSR	3300	40.64	81.19
BLOODHOUND	108	UK	5060	64.89	77.98
TAN-SAM	3.5	JAPAN	220	1.75	125.89
STINGER	3	USA	35	0.21	168.47
HQ-61	6	CHINA	660	8.33	79.19
GECKO	8	USSR	418	4.04	103.45

TABLE A-3B: WORLD SURAFCE-TO-AIR MISSILES(CONT)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
SM2 MR BLKII	80	USA	1561	15.54	100.45
SM2 ER BLKII	90	USA	3284	26.27	124.99
GLADIATOR	54	USSR	4400	49.85	88.27
GASKIN	4	USSR	66	0.74	89.02
GUIDELINE	27	USSR	5070	110.27	45.98
GOA	16	USSR	1320	52.92	24.94
GOPHER	5	USSR	121	0.89	135.62
HN-5	1	CHINA	20	0.14	148.15
SM1 MR BLKIV	20	USA	1358	14.74	92.12
GADFLY	16.2	USSR	1430	23.89	59.85
GRAIL	4	USSR	20	0.14	148.05
TARTAR	20	USA	1330	14.94	89.00
MISTRAL AA	3	FRANCE	33.4	0.42	80.09
GAINFUL	17	USSR	1212	19.29	62.83
GALOSH	178	USSR	72000	3688.32	19.52
SM1 ER BLKV	40	USA	2969	27.08	109.65
GRUMBLE	53	USSR	3300	40.64	81.19
MISTRAL SA	3	FRANCE	33.4	0.42	80.09
SEA SPARROW	20	USA	507	4.66	108.88
MASURCA	27	FRANCE	4600	37.43	122.89
GANEF	38	USSR	3960	153.96	25.72
GAMMON	162	USSR	22000	214.28	102.67
AVERAGE			3306	104.85	97.06

TABLE A-4A: WORLD SURFACE-TO-SURFACE MISSILES(PARTIAL)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
SSBS	1886	FRANCE	56760	865.53	65.58
TOW 2B	2	USA	50	0.77	64.96
SS-N-21	1617	USSR	3300	55.32	59.65
SPANKER	5930	USSR	143000	4156.04	34.40
SS-N-8	4312	USSR	44900	973.32	46.13
HARPOON	62	USA	1503	15.11	99.49
SM1 MR BLKIV	10	USA	1358	14.74	92.11
TASM	250	USA	3206	45.96	69.75
TLAM-C	1500	USA	3366	45.96	73.23
SM2 MR BLKI	10	USA	1385	14.64	94.59
TARTAR	10	USA	1330	14.94	89.01
LANCE	67	USA	3351	51.40	65.19
STILLETO	5300	USSR	171600	4678.84	36.68
STINGRAY	4312	USSR	44500	1263.06	35.23
SWINGFIRE	2	UK	22	0.99	22.23
PERSHINGII	970	USA	16436	303.07	54.23
MLRS	18	USA	680	5.74	118.40
STRIX	4.3	SWEDEN	35.2	0.34	103.75
SM2 MR BLKII	10	USA	1561	15.54	100.45
POSEIDEN	2500	USA	65000	1026.45	63.32
MATHOGO	1	ARGENTINA	25	0.23	107.17
GABRIELII	20	ISRAEL	1144	10.64	107.48
GABRIELIII	20	ISRAEL	1232	11.88	103.71

TABLE A-4B: WORLD SURFACE-TO-SURFACE MISSILES (CONT)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
GABRIEL LR	108	ISRAEL	2112	23.71	89.09
HARPON	1	FRANCE	66	0.79	83.78
HOT SS	1	FRANCE	52	0.53	97.95
GABRIEL I	11	ISRAEL	946	10.45	90.49
KAM-9	2	JAPAN	73	1.00	72.50
MSS 1.1	1	ITALY	32	0.56	56.59
MALAFON	7	FRANCE	3300	69.96	47.17
MAPATS	2.5	ISRAEL	41	0.94	43.50
KAM-3D	1	JAPAN	35	0.42	83.19
MILAN	1	FRANCE	15	0.18	83.19
EXOCET MM-40	38	FRANCE	1870	18.05	103.57
SILKWORM	54	CHINA	5060	126.89	39.88
BANTAM	1	SWEDEN	25	0.35	71.91
BILL	1	SWEDEN	24	0.59	39.89
COBRA	1	FRG	23	0.22	103.59
CSS-1	647	CHINA	57200	1463.19	39.09
ASROC	5	USA	957	14.35	66.69
CSS-4	6468	CHINA	440000	9911.78	44.39
DRAGON	0.5	USA	24	1.76	13.86
ERYX	0.5	FRANCE	32	0.59	53.82
EXOCET MM-38	23	FRANCE	1617	16.25	99.51
CSS-2	1348	CHINA	59400	3569.86	16.64
SKIFF	4473	USSR	48400	1254.86	38.57

TABLE A-4C: WORLD SURFACE-TO-SURFACE MISSILES (CONT)

NAME	RANGE	COUNTRY	WEIGHT	VOLUME	DENS
	NM		lbs	FT^3	lbs/FT^3
MINUTEMAN	7007	USA	75960	1744.66	43.54
SAWFLY	1617	USSR	41800	877.58	47.63
SCALE	485	USSR	19800	336.98	58.75
SCALPEL	5390	USSR	210000	3643.79	57.63
SCARAB	65	USSR	6600	121.29	54.41
SCUD B	161	USSR	13860	227.21	61.00
SAVAGE	5066	USSR	77000	1615.69	47.66
SEGO	7007	USSR	106000	3053.65	34.71
SEPAL	243	USSR	12000	269.42	44.54
SERB	862	USSR	36300	535.31	67.81
SICKEL	5390	USSR	77000	1453.13	52.99
SCUD C	242	USSR	13860	267.89	51.73
SIREN	60	USSR	6600	91.73	71.95
SANDBOX	296	USSR	11000	328.42	33.49
SATAN	8624	USSR	484000	13652.36	35.45
MSBS M-4	2426	FRANCE	77000	1128.41	68.24
OTOMAT	92	ITALY	1694	25.79	65.66
PEACE	5983	USA	194590	3296.79	59.02
PENGUIN	14.5	NORWAY	748	6.23	119.98
MSBS M-20	1617	FRANCE	49000	643.02	76.20
PLUTON	65	FRANCE	5331	97.32	54.77
RED ARROW	1.6	CHINA	24.6	0.36	68.21
SAGGER SS	1	USSR	25	0.35	71.05
SAMLET	108	USSR	6600	274.75	24.02
AVERAGE			38769	910.70	65.49

2. Range Designation Categories

TABLE A-5A: WORLD SHORT RANGE MISSILES(PARTIAL)

NAME	WEIGHT	VOLUME	DENSITY
	lbs	FT^3	lbs/FT^3
ASPIDE	485	4.66	104.16
ATOLL	154	1.16	133.21
APHID	121	0.89	135.62
TAN-SAM	220	1.75	125.89
ASH	860	13.35	64.41
MLRS	680	5.74	118.40
BILL	23.5	0.59	39.89
PWR GBU-15TV	2981	22.76	130.95
BLOWPIPE	32	0.22	148.16
SWATTER	60	0.65	92.60
BANTAM	25.3	0.35	71.91
RAM	164	1.27	128.67
BARAK	189	2.04	92.84
APEX	704	3.39	207.13
MAVERICK IR	669	6.39	104.65
STINGER	35	0.21	168.49
SIDEWINDER	189	1.30	145.13
SHRIKE	409.10	3.56	114.78
TOW 2B	99	1.43	69.39
HELLFIRE	3021.55	23.20	130.23
PWR GBU-15 IR	50	0.77	64.96
MAVERICK LASER	642	6.39	100.42
CHAPARRAL	190	1.32	144.36
AS.15TT	220	2.12	103.75
AS.30	1144	12.16	94.05

TABLE A-5B: WORLD SHORT RANGE MISSILES(CONT)

NAME	WEIGHT	VOLUME	DENSITY
	lbs	FT^3	lbs/FT^3
ASROC	957	14.35	66.69
STRIX	35	0.34	103.75
SWINGFIRE	22	0.99	22.23
HN-5	20	0.14	148.05
GASKIN	66	0.74	89.02
MALAFON	3300	69.96	47.17
MAPATS	41	0.94	43.50
MARTE	726	5.66	128.33
MARTIN PESCADOR	308	3.69	83.37
MATHOGO	25	0.23	107.18
MAGIC	200	1.77	113.18
GOA	1320	52.91	24.95
MISTRAL	33	0.42	80.09
GECKO	418	4.04	103.45
MILAN	15	0.18	83.19
PENGUIN MK-3	748	6.23	119.98
MAA-1	198	1.81	109.61
MSS 1.1	32	0.57	56.59
HQ-61	660	8.33	79.19
JAVELIN	34	0.22	156.49
KAM-3D	35	0.41	83.19
KAM-9	73	1.00	72.50
HOT SS	52	0.53	97.96
KERRY	2640	9.03	292.30
GRAIL	20	0.14	148.05
GOPHER	121	0.89	135.62
KUKRI	161	1.21	133.46
HARPON	66	0.79	83.78
COBRA	23	0.22	103.59

TABLE A-5C: WORLD SHORT RANGE MISSILES (CONT)

NAME	WEIGHT	VOLUME	DENS
	lbs	FT^3	lbs/FT^3
PENGUIN SSM	748	6.23	119.98
SA-N-4	418	4.04	103.45
GABRIEL I	946	10.45	90.49
SEACAT	150	1.38	108.27
HOT AS	52	0.53	97.96
ERYX	32	0.59	53.82
GADFLY	1430	23.89	59.85
SEAWOLF	176	1.84	95.77
DRAGON	24	1.76	13.87
SHAFRIR	205	1.61	127.33
PYTHON	264	1.92	137.20
SEA SKUA	319	4.12	77.39
CROTALE	178	1.88	94.43
SAGGER	25	0.35	71.05
ANAB	605	0.52	70.97
R.530	423	6.87	61.57
RAPIER	94	0.92	102.15
RAY RIDER	52.4	0.54	96.98
PL-5B	187	1.19	156.65
RED ARROW	25	0.36	68.21
ROLAND	149	1.55	96.05
SAAB 04E	1350	29.35	45.99
SAAB 05A	671	9.27	72.40
GAINFUL	1212	19.29	62.83
AVERAGE	463	5.60	101.67

TABLE A-6: WORLD MEDIUM RANGE MISSILES

NAME	WEIGHT	VOLUME	DENS
	lbs	FT^3	lbs/FT^3
GANEF	3960	153.96	25.72
SM1MR BLKIV	1358	14.74	92.12
HARM	795	7.39	107.52
SEA DART	1210	22.32	54.21
PENGUIN MK2 MOD7	763	6.62	115.33
EXOCET AM-39	1434	14.63	97.99
GABRIEL III	1232	11.88	103.71
ASPIDE	485	4.66	104.15
EXOCET MM-38	1617	16.25	99.51
GABRIEL II	1144	10.64	107.48
EXOCET MM-40	1870	18.06	103.57
AMRAAM	339	3.39	99.92
GABRIEL III AS	1320	11.97	110.24
SA-N-6	3300	40.64	81.19
SUPER 530	550	7.38	74.53
SKIPPER II	1280	28.35	45.15
MASURCA	4600	37.43	122.89
GUIDELINE	5070	110.27	45.98
SKYFLASH	425	4.62	92.03
MARTEL	1170	18.32	63.88
SM2MR BLKI	1385	14.64	94.59
HAWK	1398	18.66	74.92
KORMORAN	1320	13.68	96.46
TARTAR	1330	14.94	89.00
SEA SPARROW	507	4.66	108.88
SM1ER BLKV	2969	27.08	109.65
AVERAGE	1647	24.51	89.25

TABLE A-7A: WORLD LONG RANGE MISSILES(PARTIAL)

NAME	WEIGHT	VOLUME	DENSITY
	lbs	FT^3	lbs/FT^3
SEA EAGLE	1320	18.32	72.07
SAMLET	6600	274.74	24.02
SANDBOX	11000	328.42	33.49
SATAN	484000	13652.36	35.45
SAVAGE	77000	1615.69	47.66
SAWFLY	41800	877.57	47.63
KELT	6600	213.24	30.95
SCALPEL	210000	3643.79	57.63
SCARAB	6600	121.29	54.41
SCUD B	13860	227.20	61.00
SCUD C	13860	267.89	51.74
SCALEBOARD	19800	336.98	58.76
PLUTON	5331	97.32	54.78
RBS-15	1316	28.75	45.77
KINGFISH	10580	224.18	47.19
KIPPER	9240	204.75	45.13
KITCHEN	13200	262.24	50.33
MINUTEMAN	75960	1744.66	43.54
PERSHING II	16436	303.07	54.23
MSBS M-4	77000	1128.41	68.24
OTOMAT	1694	25.79	65.66
PEACEKEEPER	194590	3296.79	59.02
MSBS M-20	49000	643.01	76.20
SEGO	106000	3053.65	34.71
SPARROW III	508	4.54	111.86
PHOENIX	1030	15.95	64.56
SLAM	1332	14.79	90.07
HARPOON AIR LN	1145	12.54	91.27
SM2ER BLKII	3284	26.27	124.99
SEPAL	12000	269.42	44.54
TASM	3206	45.96	69.75
SM2MR BLKII	1561	15.54	100.45

TABLE A-7B: WORLD LONG RANGE MISSILES (CONT)

NAME	WEIGHT	VOLUME	DENSITY
	lbs	FT^3	lbs/FT^3
TLAM-C	3366	45.96	73.23
LANCE	3351	51.40	65.19
HARPOON SHIP LN	1503	15.11	99.49
PATRIOT	2200	24.17	91.01
STILLETO	171600	4678.84	36.67
STINGRAY	44500	1263.06	35.23
SERB	36300	535.31	67.81
SICKEL	77000	1453.13	52.99
SIREN	6600	91.73	71.95
SKIFF	48400	1254.85	38.57
KANGAROO	24200	1429.04	16.93
SRAM	2222	26.51	83.83
SSBS	56760	865.53	65.58
SS-N-8	44900	973.32	46.13
SS-N-21	3300	55.32	59.65
SPANKER	143000	4156.04	34.41
ALCM	2816	65.03	43.30
GRUMBLE	3300	40.64	81.19
ASM-1	1342	12.45	107.80
GAMMON	22000	214.27	102.67
GALOSH	72000	3688.32	19.52
ASMP	1848	19.90	92.84
GABRIEL LR	2112	23.71	89.09
CSS-1	57200	1463.19	39.09
SILKWORM	5060	126.88	39.88
GLADIATOR	4400	49.86	88.26
ARMAT	1210	16.86	71.78
BLOODHOUND	5060	64.89	77.98
CSS-4	440000	9911.78	44.39
CSS-2	59400	3569.86	16.64
POSEIDON	65000	1026.45	63.32
AVERAGE	45854	1114.42	60.84

B. U.S. MISSILES DATA BASE

1. Overall Specifications by Mission Area Categories

TABLE A-8: SELECTED U.S. AIR-TO-AIR MISSILES

NAME	RNG	SPD	LEN	DIAM	WT	VOL	DENS
	NM	MACH	FT	FT	lbs	FT^3	lb/FT^3
AMRAAM	35	4	12.00	0.60	339	3.39	99.92
SPARROW III	50	2.5	11.80	0.70	508	4.54	111.86
PHOENIX	100	5	13.00	1.25	1030	15.95	64.56
STINGER	3	1.7	5.00	0.23	35	0.21	168.49
SIDE WINDER	2	2	9.40	0.42	189	1.30	145.13
AVERAGE			10.24	0.64	420	5.08	117.99

TABLE A-9: SELECTED U. S. AIR-TO-SURFACE MISSILES

NAME	RNG	SPD	LEN	DIAM	WT	VOL	DENS
	NM	MACH	FT	FT	lbs	FT^3	lb/FT^3
SHRIKE	9	2	10.11	0.67	409	3.56	114.78
MAVIR	14	1	8.14	1.00	669	6.39	104.65
MAVLSR	14	1	8.14	1.00	642	6.39	100.42
GBU15IR	16	1.6	13.13	1.50	3022	23.20	130.23
TOW-2B	2	0.8	3.92	0.50	50	0.77	64.96
SLAM	50	0.75	14.75	1.13	1332	14.79	90.07
GBU15TV	16	1.6	12.88	1.50	2981	22.76	130.95
HELLFRE	4	1	5.40	0.58	99	1.43	69.39
HARPOON	62	0.75	12.62	1.13	1145	12.54	91.27
HARM	43	3.5	13.67	0.83	795	7.39	107.52
AVERAGE			10.28	0.98	1114	9.92	100.42

TABLE A-10: SELECTED U.S. SURFACE-TO-AIR MISSILES

NAME	RNG	SPD	LEN	DIAM	WT	VOL	DENS
	NM	MACH	FT	FT	lbs	FT^3	lb/FT^3
SM2MR BLKII	80	3	15.5	1.13	1561	15.54	100.45
SM2ER BLKII	90	2.5	26.2	1.13	3284	26.27	124.98
STINGER	3	1.7	5.0	0.23	35	0.21	168.49
SM1ER BLKV	40	2	27.0	1.13	2969	27.08	109.65
SEA SPARROW	20	1.3	12.1	0.70	507	4.66	108.88
TARTAR	20	2	14.9	1.13	1330	14.94	89.00
SM1MR BLKIV	20	2	14.7	1.13	1358	14.74	92.12
SM2MR BLKI	40	3	14.6	1.13	1385	14.64	94.59
CHAPPA RRAL	3	2.5	9.5	0.42	190	1.32	144.36
RAM	5	2	9.2	0.42	164	1.27	128.67
HAWK	22	2.5	16.5	1.20	1398	18.66	74.92
PATRIOT	62	3.4	17.4	1.33	2200	24.17	91.01
AVERAGE			15.2	0.92	1365	163.5	110.59

TABLE A-11: SELECTED U. S. SURFACE-TO-SURFACE MISSILES

NAME	RNG	SPD	LEN	DIAM	WT	VOL	DENS
	NM	MACH	FT	FT	lbs	FT^3	lb/FT^3
TASM	250	0.7	20.3	1.70	3206	45.96	69.75
TLAM-C	1500	0.7	20.3	1.70	3366	45.96	73.23
TOW 2B	2	0.8	3.9	0.50	50	0.77	64.96
SM2MR BLKI	10	3	14.6	1.13	1385	14.64	94.59
TARTAR	10	2	14.9	1.13	1330	14.94	89.01
LANCE	67	3	20.2	1.80	3351	51.40	65.19
SM1MR BLKIV	10	2	14.7	1.13	1358	14.74	92.12
SM2MR BLKII	10	3	15.5	1.13	1561	15.54	100.45
HAR POON	62	0.75	15.2	1.13	1503	15.11	99.49
PERSH II	970	10	34.8	3.33	16436	303.0	54.23
MLRS	18	1.4	13.0	0.75	680	5.74	118.40
AVG			17.0	1.40	3111	47.98	83.76

2. Subsection Specifications by Mission Areas

a. Propulsion Subsection Specifications

TABLE A-12: AAM PROPULSION SUBSECTION SPECIFICATIONS

NAME	PRP LEN	PRP DIAM	PRP WT	PRP VOL	PRP DENS	Wprp/Wt
	FT	FT	lbs	FT^3	lb/FT^3	
AMRAAM	4.89	0.60	154	1.38	111.67	0.455
SPARROW III	4.95	0.70	211	1.90	110.92	0.416
PHOENIX	3.32	1.25	460	4.07	112.91	0.447
STINGER	3.25	0.23	17	0.14	125.90	0.486
SIDE WINDER	5.83	0.42	99	0.81	122.57	0.524
AVERAGE	4.45	0.64	188	1.66	116.79	0.466

TABLE A-13: ASM PROPULSION SUBSECTION SPECIFICATIONS

NAME	PRP LEN	PRP DIAM	PRP WT	PRP VOL	PRP DENS	Wprp/Wt
	FT	FT	lbs	FT^3	lb/FT^3	
SHRIKE	4.23	0.67	172	1.49	115.34	0.420
MAVIR	2.22	1.00	221	1.74	126.75	0.330
MAVLSR	2.22	1.00	221	1.74	126.75	0.344
GBU15IR	10.20	0.75	486	4.51	107.95	0.161
TOW-2B	2.17	0.50	14	0.43	32.86	0.280
SLAM	6.49	1.13	485	6.51	74.52	0.364
GBU15TV	10.20	0.75	486	4.51	107.95	0.163
HELLFIRE	1.17	0.58	33	0.31	106.76	0.333
HARPOON	6.50	1.13	478	6.46	73.91	0.417
HARM	6.96	0.83	395	3.77	104.89	0.497
AVERAGE	5.24	0.83	299	3.15	97.77	0.378

TABLE A-14: SAM PROPULSION SUBSECTION SPECIFICATIONS

NAME	PRP LEN	PRP DIAM	PRP WT	PRP VOL	PRP DENS	Wprp/Wt
	FT	FT	lbs	FT^3	lb/FT^3	
SM2MR BLKII	8.35	1.13	1072	8.37	128.02	0.687
SM2ER BLKII	18.01	1.36	2686	26.16	102.66	0.818
STINGER	3.25	0.23	17	0.14	125.90	0.486
SM1ER BLKV	19.80	1.36	2516	28.76	87.48	0.848
SEA SPARROW	4.95	0.70	211	1.90	110.92	0.417
TARTAR	6.76	1.13	790	6.78	116.53	0.594
SM1MR BLKIV	7.50	1.13	905	7.52	120.32	0.666
SM2MR BLKI	7.95	1.13	907	7.97	113.76	0.655
CHAPPARRAL	5.83	0.42	99	0.81	122.57	0.521
RAM	5.91	0.42	103	0.82	125.29	0.625
HAWK	8.83	1.20	871	9.99	87.18	0.623
PATRIOT	9.25	1.33	1302	12.85	101.32	0.592
AVERAGE	8.87	0.96	957	9.34	111.83	0.628

TABLE A-15: SSM PROPULSION SUBSECTION SPECIFICATIONS

NAME	PRP LEN	PRP DIAM	PRP WT	PRP VOL	PRP DENS	Wprp/Wt
	FT	FT	lbs	FT^3	lb/FT^3	
TASM	12.00	1.70	1785	27.24	65.54	0.557
TLAM-C	12.00	1.70	1785	27.24	65.54	0.530
TOW-2B	2.17	0.50	14	0.43	32.86	0.280
SM2MR BLKI	7.95	1.13	907	7.97	113.76	0.655
TARTAR	6.76	1.13	790	6.78	116.53	0.593
LANCE	12.15	1.80	2251	30.92	72.81	0.672
SM1MR BLKIV	7.50	1.13	905	7.52	120.32	0.666
SM2MR BLKII	8.35	1.13	1072	8.37	128.02	0.686
HARPOON SHIP LN	9.08	1.13	836	9.02	92.62	0.556
PERSHNG II	20.08	3.33	14302	174.9	81.78	0.870
MLRS	6.50	0.75	326	2.87	113.53	0.479
AVERAGE	9.50	1.40	2270	27.57	91.21	0.595

b. G/C Subsection Specifications

TABLE A-16: AAM GUIDANCE/CONTROL SUBSECTION SPECIFICATIONS

NAME	G/C LEN	G/C DIAM	G/C WT	G/C VOL	G/C DENS	Wgc/Wt	PROD STRT
	FT	FT	lbs	FT^3	PCF		YEAR
AMRAAM	5.88	0.60	120	1.66	72.33	0.355	1984
SPARROW III	4.13	0.70	134	1.59	84.56	0.264	1980
PHOENIX	6.96	1.25	300	8.54	35.12	0.291	1980
STINGER	1.19	0.23	14	0.05	283.2	0.400	1977
SIDE WINDER	2.04	0.42	30	0.28	104.4	0.156	1980
AVERAGE	4.04	0.64	120	2.42	115.9	0.293	

TABLE A-17: ASM GUIDANCE/CONTROL SUBSECTION SPECIFICATIONS

NAME	G/C LEN	G/C DIAM	G/C WT	G/C VOL	G/C DENS	Wgc/Wt	PROD START
	FT	FT	lbs	FT^3	PCF		YEAR
SHRIKE	3.42	0.67	68	1.21	57.06	0.168	1960
MAVIR	3.33	1.00	148	2.62	56.59	0.221	1982
MAVLSR	3.33	1.00	121	2.62	46.27	0.188	1982
GBU15IR	7.08	1.25	626	8.69	71.99	0.207	1990
TOW-2B	0.50	0.50	20	0.09	203.7	0.400	1990
SLAM	5.08	1.13	300	5.09	58.89	0.225	1990
GBU15TV	6.83	1.25	585	8.38	69.74	0.196	1990
HELLFIRE	2.81	0.58	32	0.74	43.10	0.323	1981
HARPOON	3.11	1.13	142	3.09	45.94	0.124	1975
HARM	4.98	0.83	193	2.69	71.56	0.242	1980
AVERAGE	4.05	0.93	223	3.52	72.49	0.229	

TABLE A-18: SAM GUIDANCE/CONTROL SUBSECTION SPECIFICATIONS

NAME	G/C LEN	G/C DIAM	G/C WT	G/C VOL	G/C DENS	Wgc/Wt	PROD STRT
	FT	FT	lbs	FT^3	PCF		YEAR
SM2MR BLKII	5.64	1.13	242	5.66	42.77	0.155	1983
SM2ER BLKII	6.10	1.13	200	6.12	32.69	0.061	1980
STINGER	1.19	0.23	14	0.05	283.17	0.400	1977
SM1ER BLKV	5.26	1.13	200	5.27	37.91	0.067	1970
SEA SPARROW	4.13	0.70	134	1.59	84.56	0.265	1980
TARTAR	6.52	1.13	310	6.53	47.41	0.233	1960
SM1MR BLKIV	5.26	1.13	200	5.27	37.91	0.147	1970
SM2MR BLKI	5.50	1.13	230	5.52	41.75	0.166	1983
CHAPP ARRAL	2.54	0.42	28	0.35	79.57	0.147	1976
RAM	1.92	0.42	29	0.27	108.35	0.176	1984
HAWK	6.47	1.20	215	7.32	29.39	0.154	1969
PATRIOT	6.07	1.33	257	8.43	30.48	0.117	1979
AVERAGE	4.72	0.92	172	4.37	71.33	0.174	

TABLE A-19: SSM GUIDANCE/CONTROL SUBSECTION SPECIFICATIONS

NAME	G/C LEN	G/C DIAM	G/C WT	G/C VOL	G/C DENS	Wgc/Wt	PROD STRT
	FT	FT	lbs	FT^3	PCF		YEAR
TASM	4.37	1.70	250	9.92	25.20	0.078	1979
TLAM-C	4.37	1.70	410	9.92	41.33	0.122	1979
TOW-2B	0.50	0.50	20	0.09	203.72	0.400	1990
SM2MR BLKI	5.50	1.13	230	5.52	41.75	0.166	1983
TARTAR	6.52	1.13	310	6.53	47.71	0.233	1960
LANCE	4.00	1.80	36	10.17	3.53	0.011	1972
SM1MR BLKIV	5.26	1.13	200	5.27	37.91	0.147	1970
SM2MR BLKII	5.64	1.13	242	5.65	42.76	0.155	1983
HARPOON	3.11	1.13	142	3.09	45.94	0.094	1975
PERSHNG II	7.64	2.66	895	42.45	21.08	0.054	1980
MLRS	0.00	0.00	0.0	0.00	0.00	0.00	1980
AVERAGE	4.69	1.40	274	9.86	51.09	0.146	

NOTE: MLRS NOT CONSIDERED IN AVERAGE

c. Warhead Subsection Specifications

TABLE A-20: AAM WARHEAD SUBSECTION SPECIFICATIONS

NAME	W/H LEN	W/H DIAM	W/H WT	W/H VOL	W/H DENS	Wwh/Wt
	FT	FT	lbs	FT^3	PCF	
AMRAAM	0.92	0.60	44	0.26	170.50	0.131
SPARROW III	1.32	0.70	85	0.51	167.52	0.167
PHOENIX	2.68	1.25	184	3.29	55.95	0.179
STINGER	0.56	0.23	4	0.02	171.93	0.114
SIDE WINDER	1.13	0.42	28	0.16	178.86	0.148
AVERAGE	1.32	0.64	69	0.85	148.95	0.148

TABLE A-21: ASM WARHEAD SUBSECTION SPECIFICATIONS

NAME	W/H LEN	W/H DIAM	W/H WT	W/H VOL	W/H DENS	Wwh/Wt
	FT	FT	lbs	FT^3	PCF	
SHRIKE	2.46	0.67	149	0.87	171.80	0.364
MAVIR	2.59	1.00	300	2.03	147.48	0.448
MAVLSR	2.59	1.00	300	2.03	147.48	0.467
GBU15IR	6.18	1.50	1910	10.92	174.86	0.632
TOW-2B	1.25	0.50	16	0.25	65.19	0.320
SLAM	3.02	1.13	497	3.03	164.10	0.373
GBU15TV	6.18	1.50	1910	10.92	174.86	0.641
HELLFIRE	1.42	0.58	24	0.38	63.97	0.247
HARPOON	3.02	1.13	491	3.00	163.66	0.429
HARM	1.73	0.83	144	0.94	153.84	0.181
AVERAGE	3.04	0.98	574	3.44	142.72	0.410

TABLE A-22: SAM WARHEAD SUBSECTION SPECIFICATIONS

NAME	W/H LEN	W/H DIAM	W/H WT	W/H VOL	W/H DENS	Wwh/Wt
	FT	FT	lbs	FT^3	PCF	
SM2MR BLKII	2.09	1.13	185	2.09	88.29	0.118
SM2ER BLKII	2.09	1.13	185	2.09	88.55	0.057
STINGER	0.56	0.23	4	0.02	171.92	0.114
SM1ER BLKV	1.93	1.13	180	1.93	93.05	0.061
SEA SPARROW	1.32	0.70	85	0.51	167.52	0.168
TARTAR	1.64	1.13	165	1.64	100.44	0.124
SM1MR BLKIV	1.93	1.13	180	1.93	93.05	0.133
SM2MR BLKI	2.02	1.13	182	2.02	89.85	0.131
CHAPPA RRAL	1.13	0.42	28	0.16	178.85	0.147
RAM	1.37	0.42	33	0.19	172.86	0.200
HAWK	1.59	1.20	178	1.79	99.04	0.127
PATRIOT	2.08	1.33	305	2.89	105.55	0.139
AVERAGE	1.64	0.92	143	1.44	120.75	0.127

TABLE A-23: SSM WARHEAD SUBSECTION SPECIFICATIONS

NAME	W/H LEN	W/H DIAM	W/H WT	W/H VOL	W/H DENS	Wwh/Wt
	FT	FT	lbs	FT^3	PCF	
TASM	3.95	1.70	1090	8.96	121.58	0.339
TLAM-C	3.95	1.70	1090	8.96	121.58	0.324
TOW-2B	1.25	0.50	16	0.25	65.19	0.320
SM2MR BLKI	2.02	1.13	182	2.03	89.85	0.131
TARTAR	1.64	1.13	165	1.64	100.44	0.124
LANCE	4.08	1.80	1000	10.38	96.32	0.298
SM1MR BLKIV	1.93	1.13	180	1.93	93.05	0.133
SM2MR BLKII	2.09	1.13	185	2.09	88.29	0.119
HARPOON	3.02	1.13	491	3.00	163.66	0.327
PERSHING II	4.17	2.00	590	13.10	45.03	0.036
MLRS	6.58	0.75	351	2.91	120.75	0.516
AVERAGE	3.15	1.28	485	5.02	100.52	0.242

3. Missile Listing for Range Categories

TABLE A-24: MISSILES WITHIN EACH RANGE CATEGORY

SHORT RANGE	MEDIUM RANGE	LONG RANGE
SIDEWINDER	AMRAAM	PHOENIX
STINGER	HARM	SPARROW III
SHRIKE	HAWK	HARPOON AIR LN
PWR GBU-15 TV	SM1MR BLKIV	HARPOON SHIP LN
PWR GBU-15 IR	SM1ER BLKV	SLAM
TOW-2B	SEA SPARROW	SM2MR BLKI
HELLFIRE	TARTAR	SM2MR BLKII
MAVERICK LASER		SM2ER BLKII
MAVERICK IR		PATRIOT
RAM		PERSHING II
CHAPPARRAL		LANCE
		TASM
		TLAM-C

4. Wing/Fin Specifications

a. Wing/Fin Specifications by Mission Area Categories

TABLE A-25: AAM WING/FIN SPECIFICATIONS

NAME	W/F WT	TAPER RATIO	ASPECT RATIO	SWEEP ANGLE
	lbs			DEGREES
AMRAAM	2.71	0.27	2.26	55
SPARROW III	9.90	0.19	2.50	55
PHOENIX	10.00	0.00	0.56	84
SIDEWINDER	5.63	0.63	2.07	45
AVERAGE	7.06	0.27	1.88	60

NOTE:W/F WT IS THE WEIGHT OF A SINGLE WING OR FIN

TABLE A-26: ASM WING/FIN SPECIFICATIONS

NAME	W/F WT	TAPER RATIO	ASPECT RATIO	SWEEP ANGLE
	lbs			DEGREES
SHRIKE	3.43	0.25	3.74	40
SLAM	8.00	0.53	1.00	52
HELLFIRE	2.50	0.64	0.29	60
HARPOON AIR LN	8.00	0.53	1.00	52
AVERAGE	5.48	0.49	1.51	51

TABLE A-27: SAM WING/FIN SPECIFICATIONS

NAME	W/F WT	TAPER RATIO	ASPECT RATIO	SWEEP ANGLE
	lbs			DEGREES
SM2MR BLKII	8.75	0.00	4.15	30
SM2ER BLKII	8.55	0.00	4.15	30
SM1ER BLKV	8.35	0.00	3.34	22
SEA SPARROW	9.90	0.19	2.50	55
TARTAR	9.45	0.00	3.38	22
SM1MR BLKIV	8.35	0.00	3.34	22
SM2MR BLKI	8.88	0.00	3.34	22
HAWK	28.55	0.25	0.56	77
PATRIOT	12.25	0.39	0.85	60
AVERAGE	11.45	0.09	2.84	38

TABLE A-28: SSM WING/FIN SPECIFICATIONS

NAME	W/F WT	TAPER RATIO	ASPECT RATIO	SWEEP RATIO
	lbs			DEGREES
SM2 MR BLKI	8.88	0.00	3.34	22
TARTAR	9.45	0.00	3.38	22
LANCE	16.00	0.00	2.55	77
SM1MR BLKIV	8.35	0.00	3.34	22
SM2MR BLKII	8.75	0.00	4.15	30
HARPOON	8.00	0.53	1.00	52
PERSHING II	17.50	0.37	1.18	53
AVERAGE	10.99	0.13	2.71	40

b. Missile Listing for Range Categories

TABLE A-29:MISSILES WITHIN EACH RANGE CATEGORY

SHORT RANGE	MEDIUM RANGE	LONG RANGE
SIDEWINDER	AMRAAM	PHOENIX
SHRIKE	HAWK	SPARROW III
HELLFIRE	SM1MR BLKIV	HARPOON
SM1MR BLKIV SS	SEA SPARROW	SLAM
TARTAR SS	TARTAR	SM2MR BLKII
SM2MR BLKII SS	SM1ER BLKV	SM2ER BLKII
SM2MR BLKI SS	SM2MR BLKI	PATRIOT
		PERSHING II
		LANCE

APPENDIX B - FIGURES

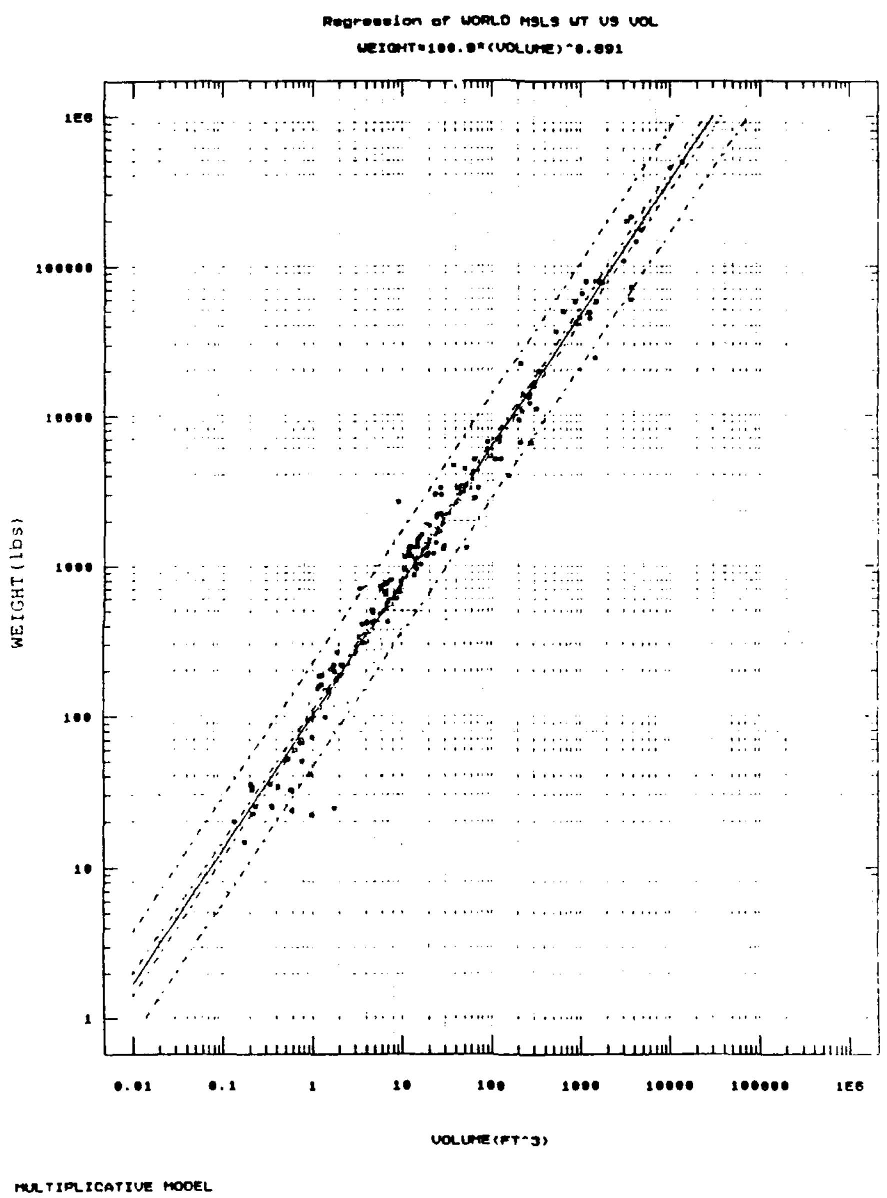

Figure B-1: Overall Missile Weight vs Volume

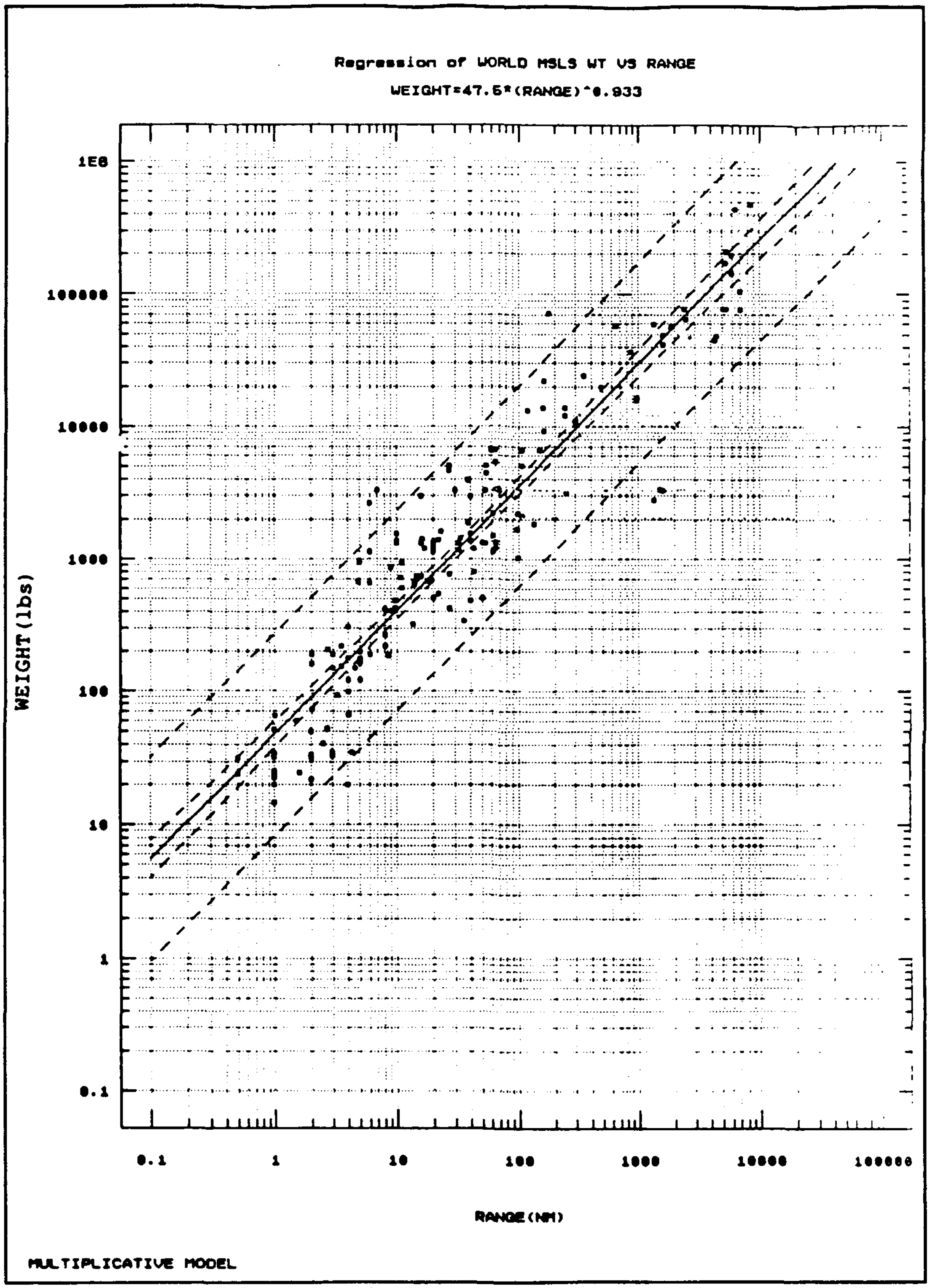

Figure B-2: Overall Weight vs Range

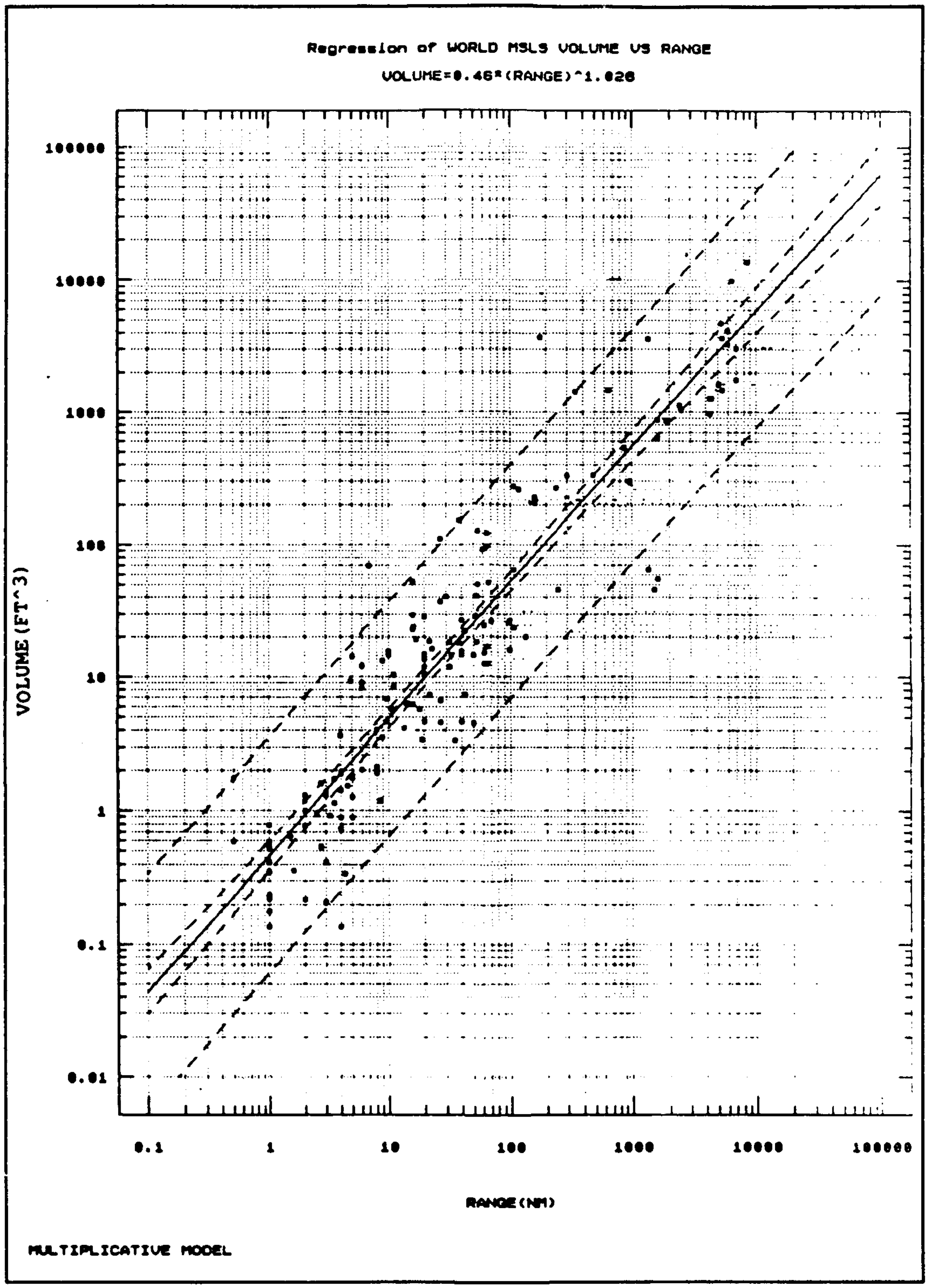

Figure B-3: Overall Volume vs Range

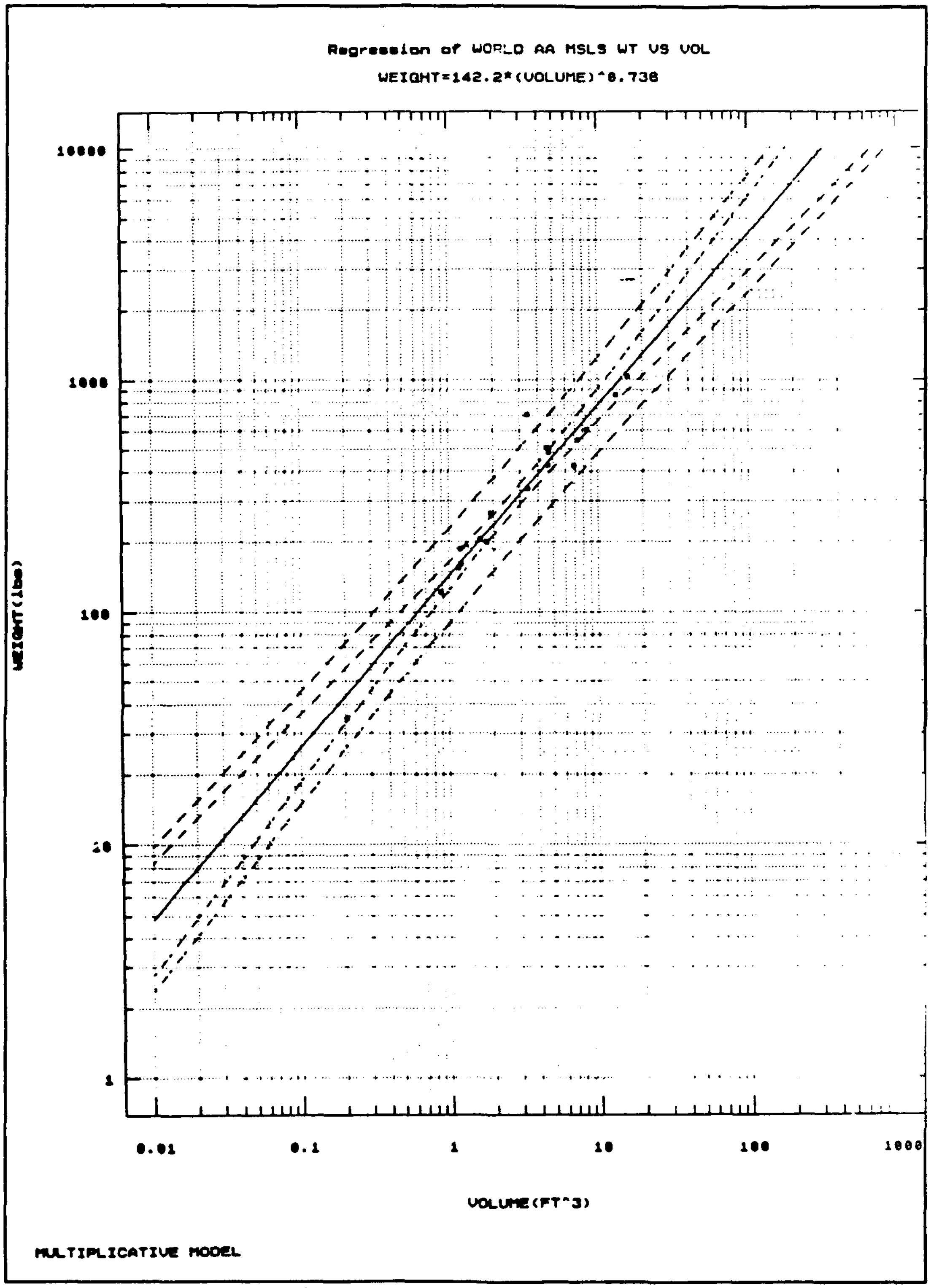

Figure B-4: AAM Weight vs Volume

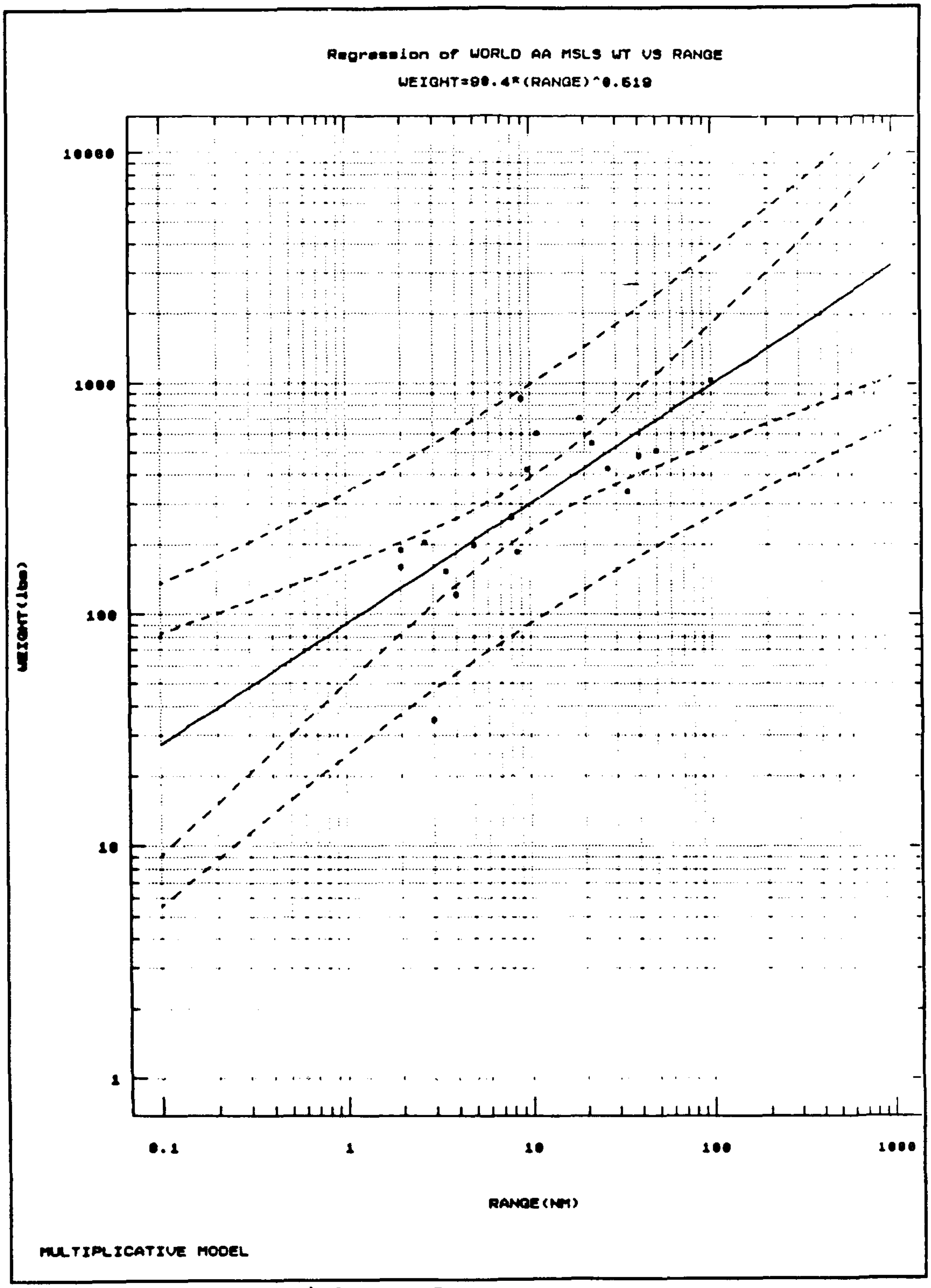

Figure B-5: AAM Weight vs Range

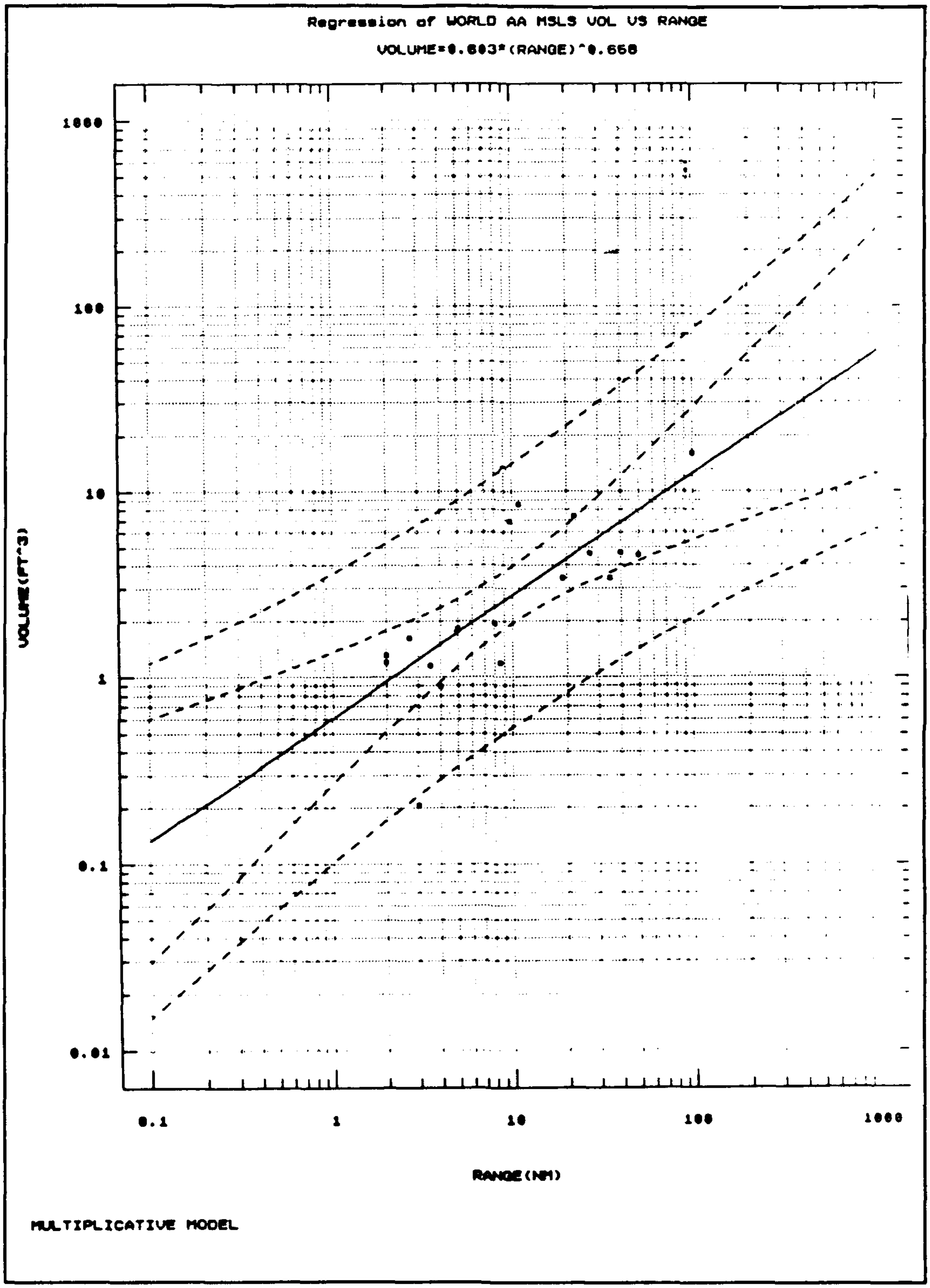

Figure B-6: AAM Volume vs Range

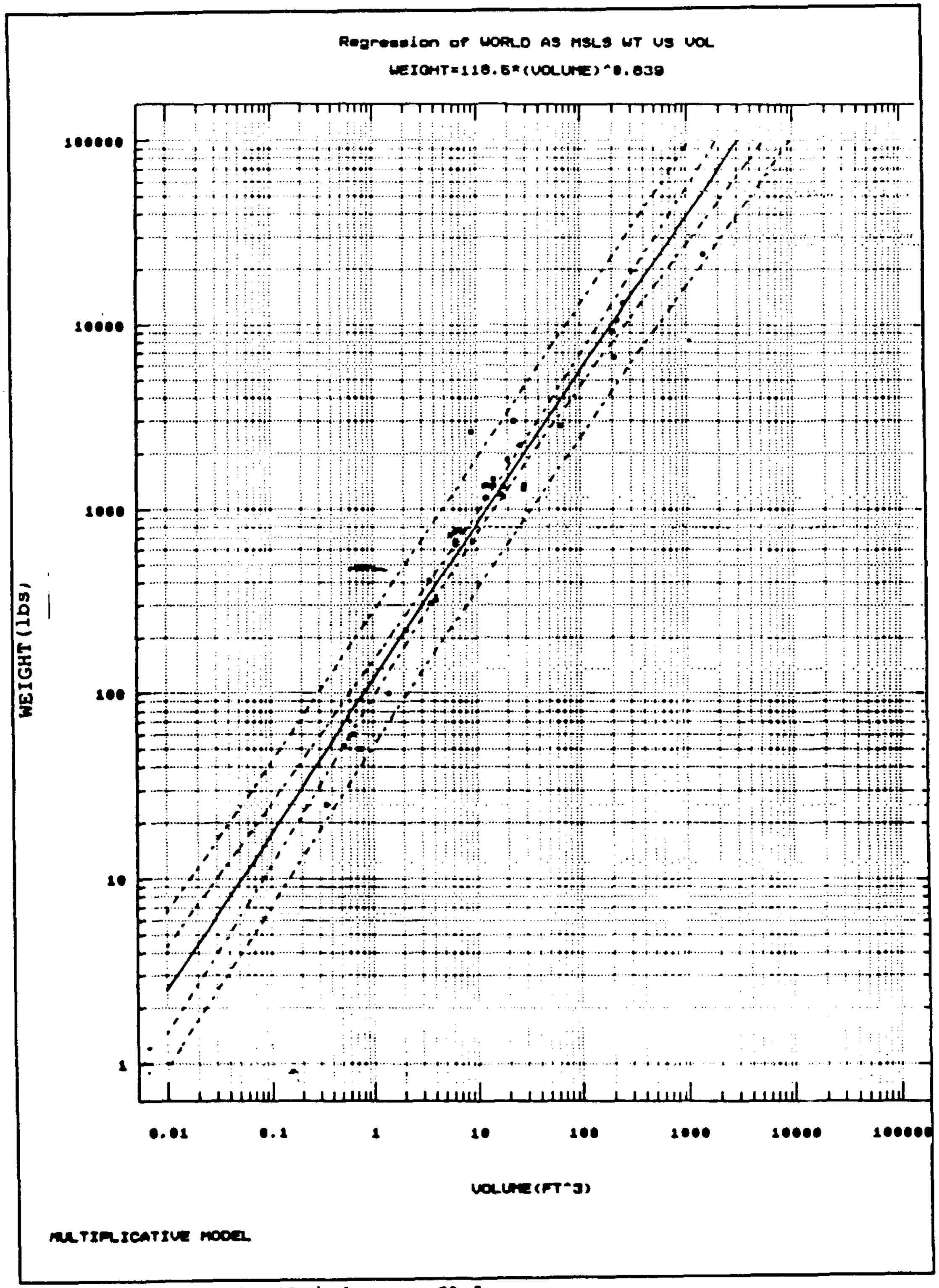

Figure B-7: ASM Weight vs Volume

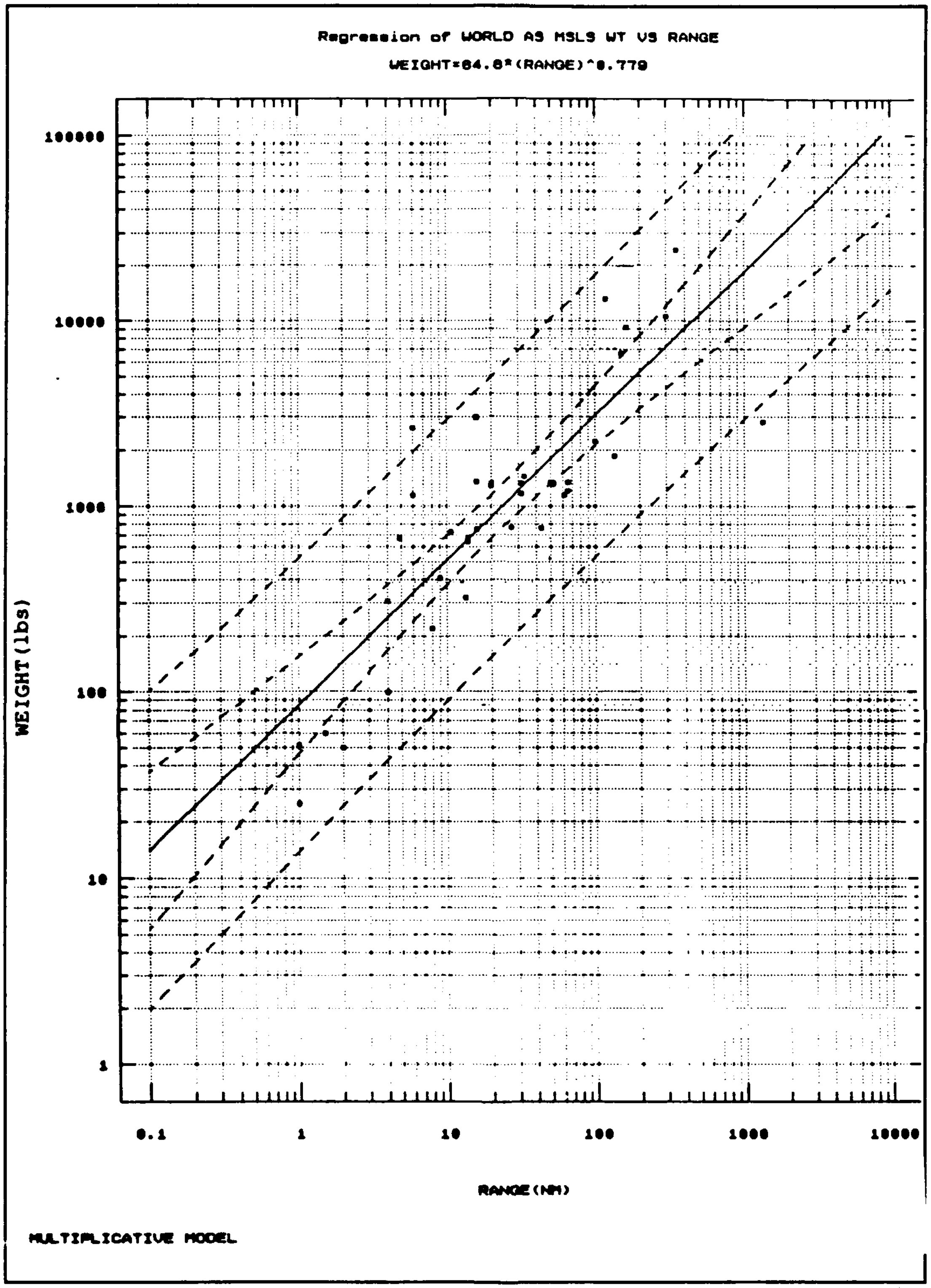

Figure B-8: ASM Weight vs Range

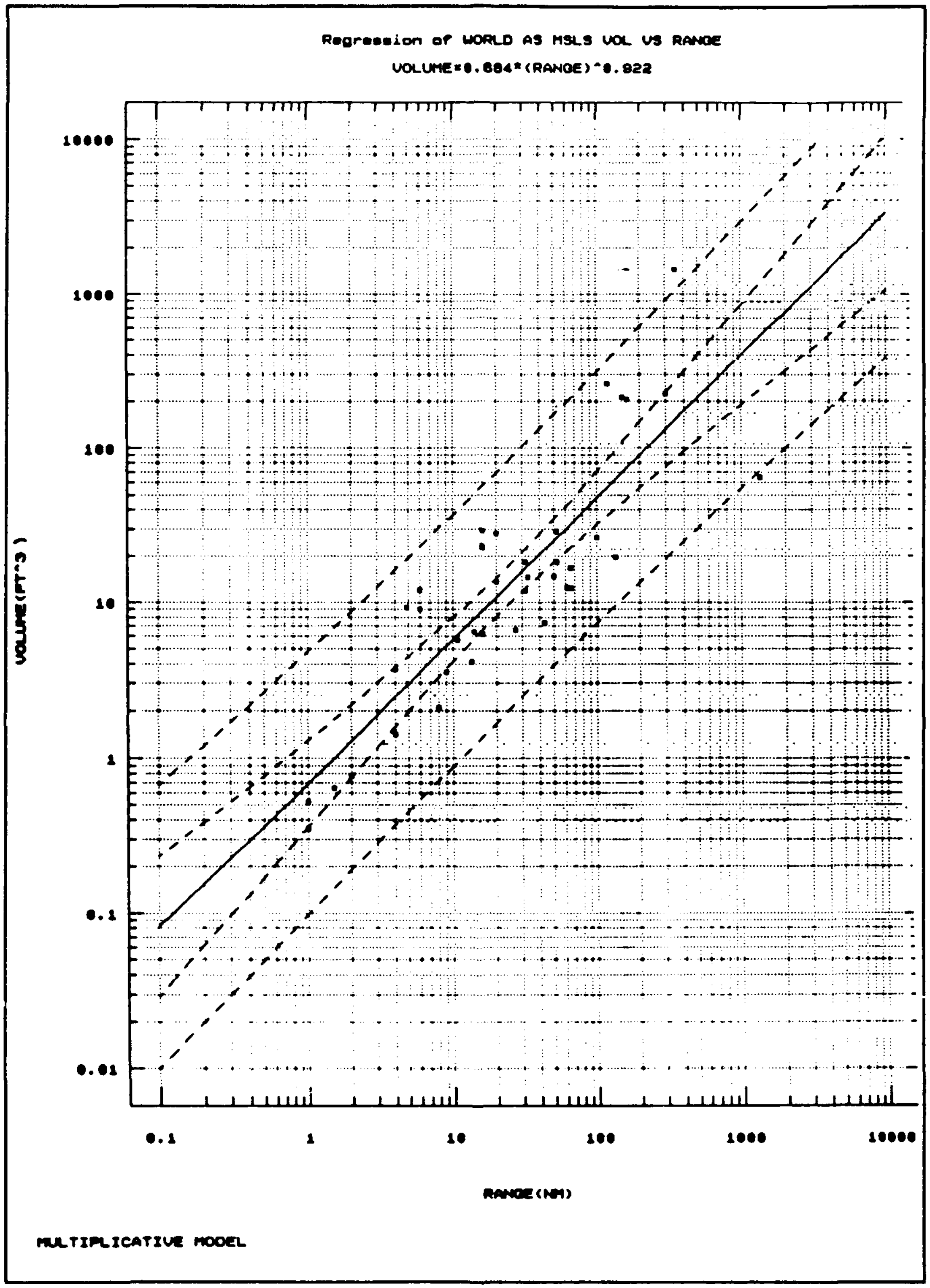

Figure B-9: ASM Volume vs Range

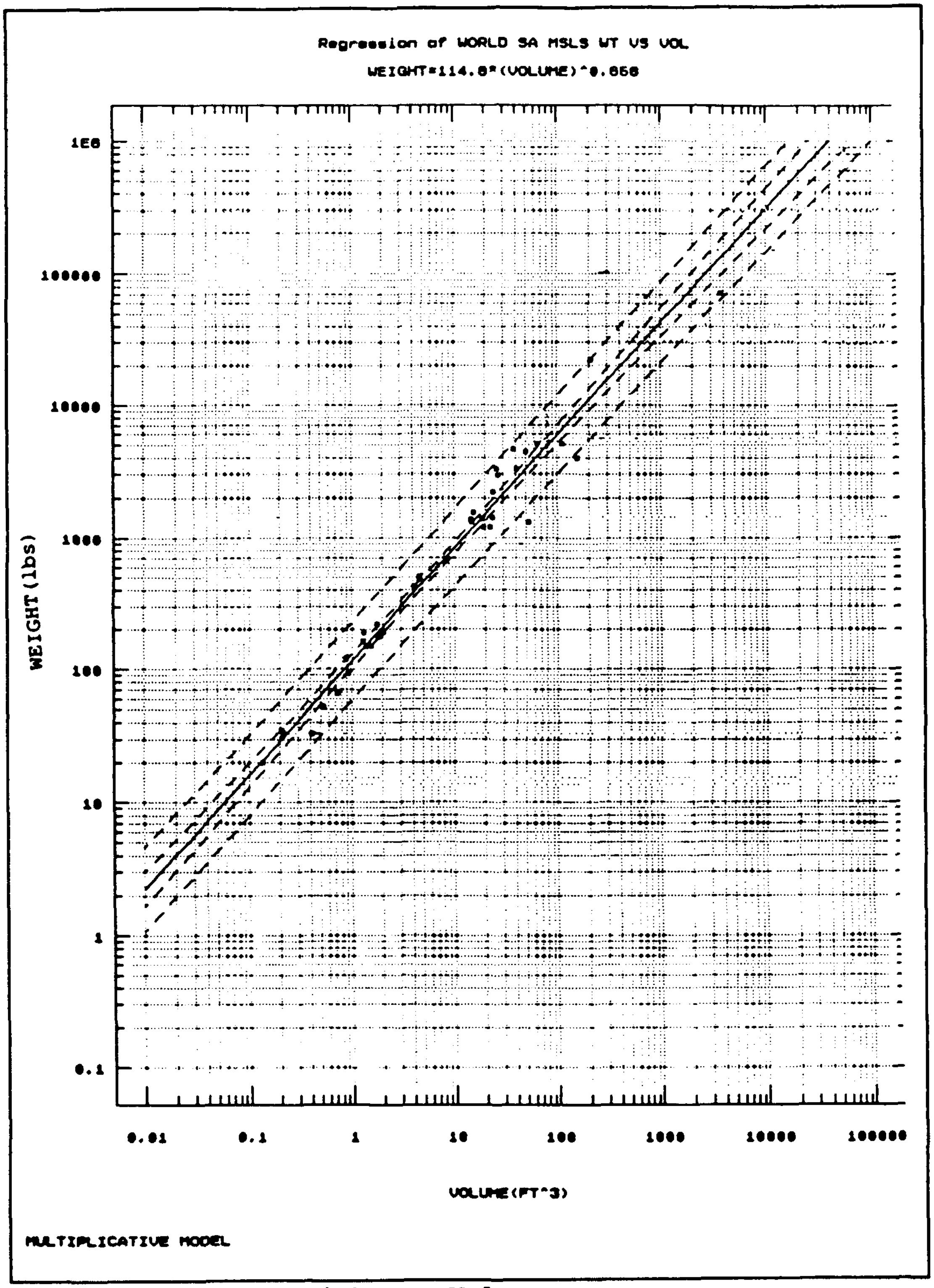

Figure B-10: SAM Weight vs Volume

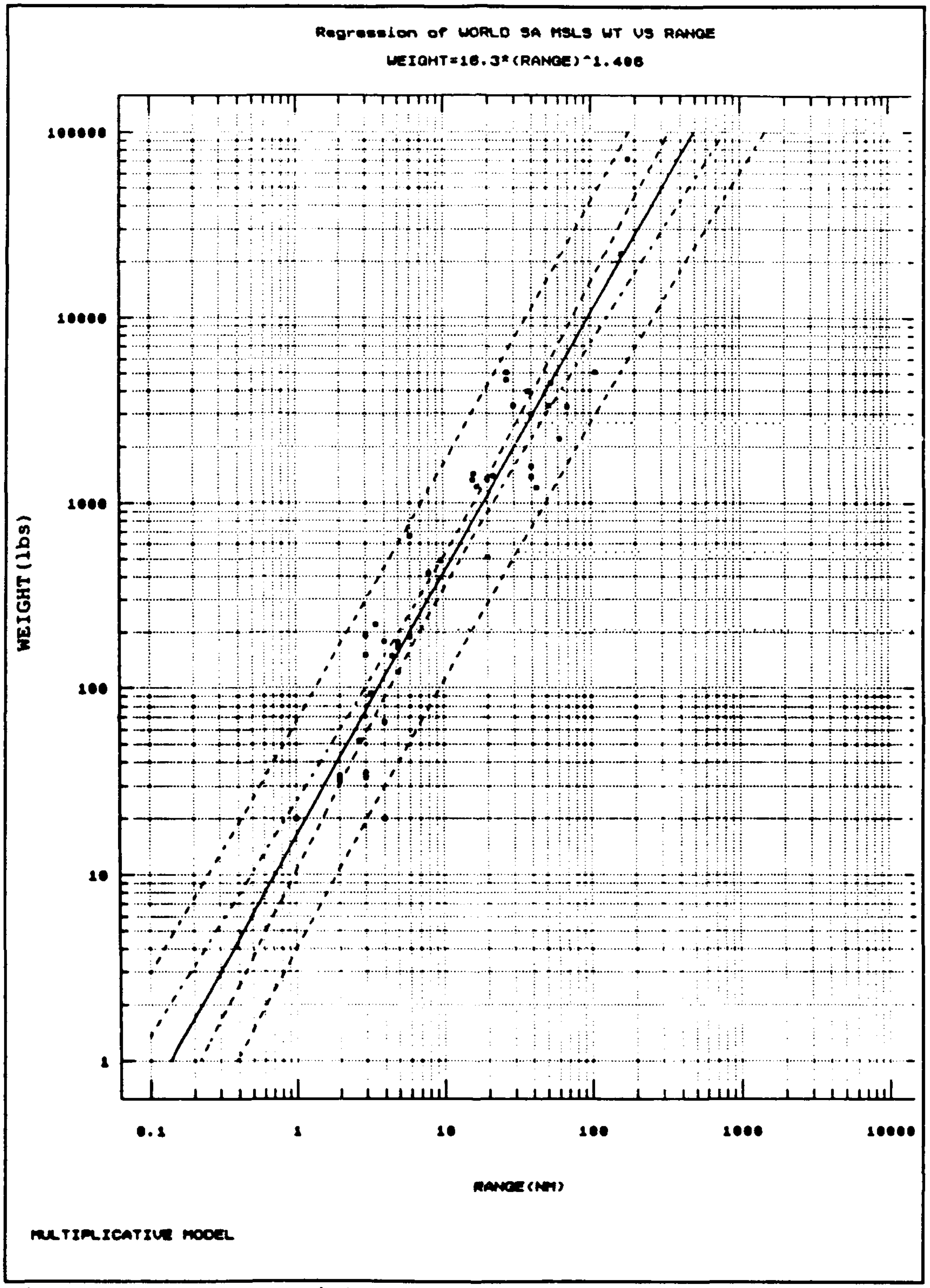

Figure B-11: SAM Weight vs Range

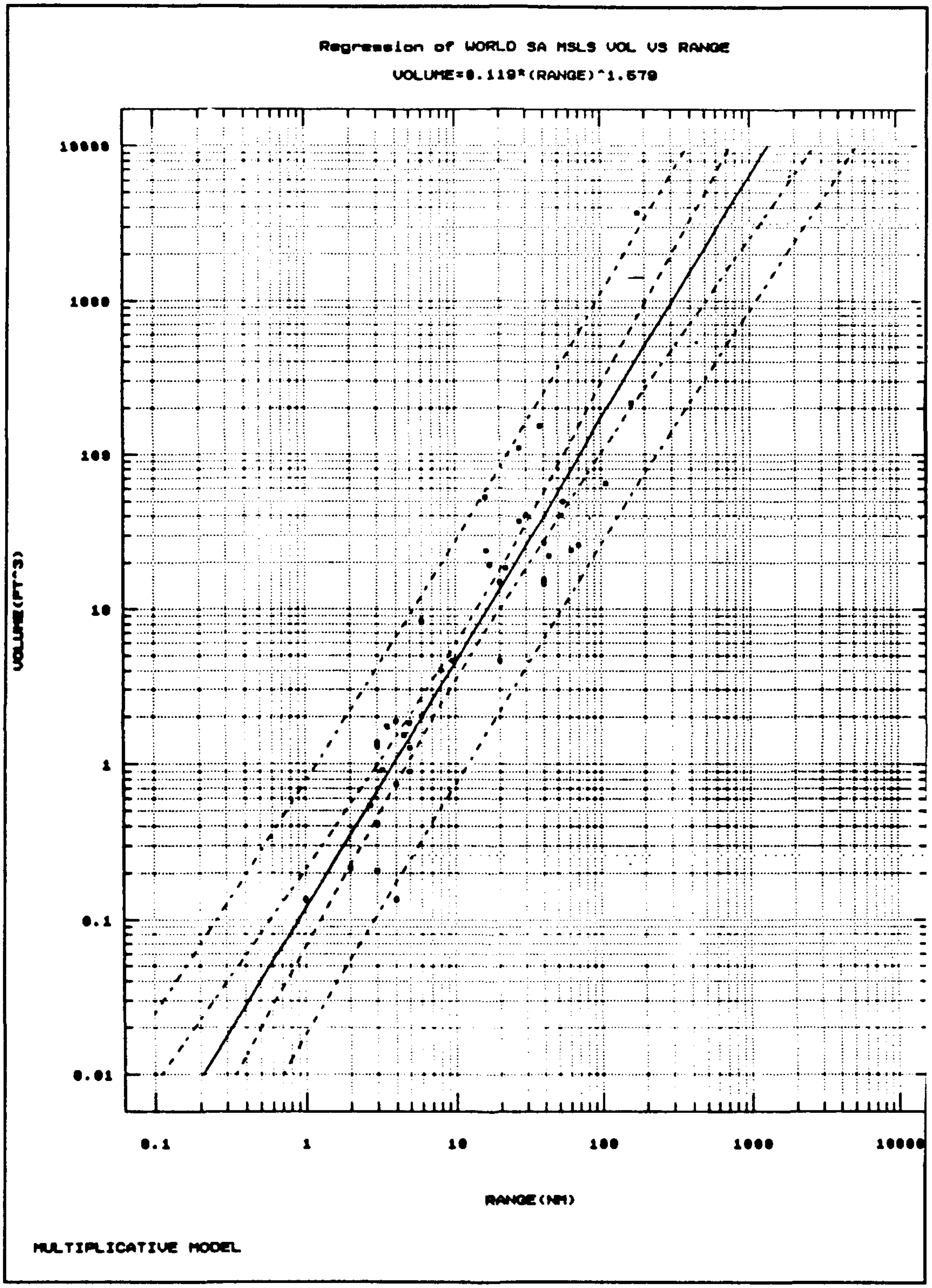

Figure B-12: SAM Volume vs Range

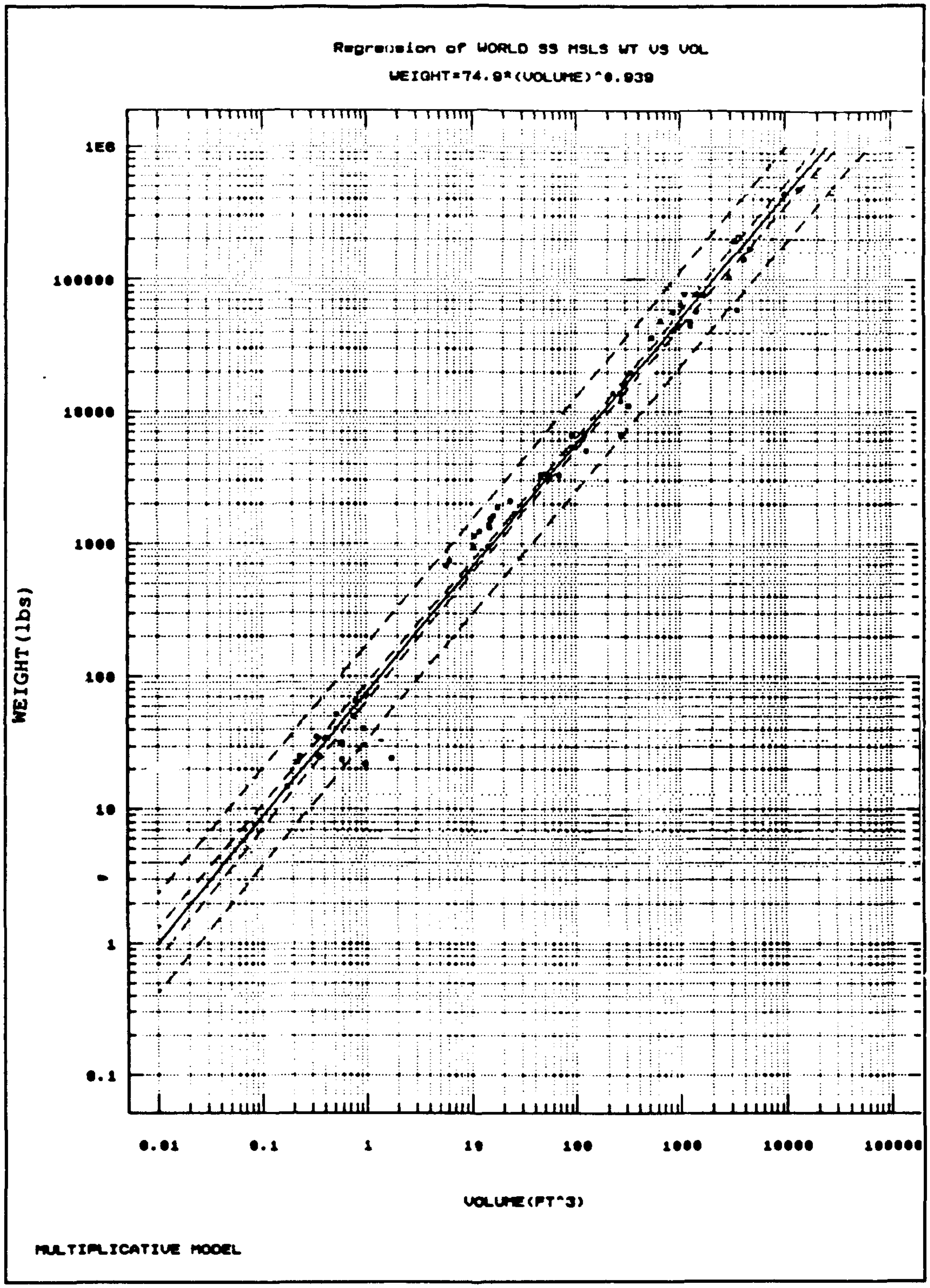

Figure B-13: SSM Weight vs Volume

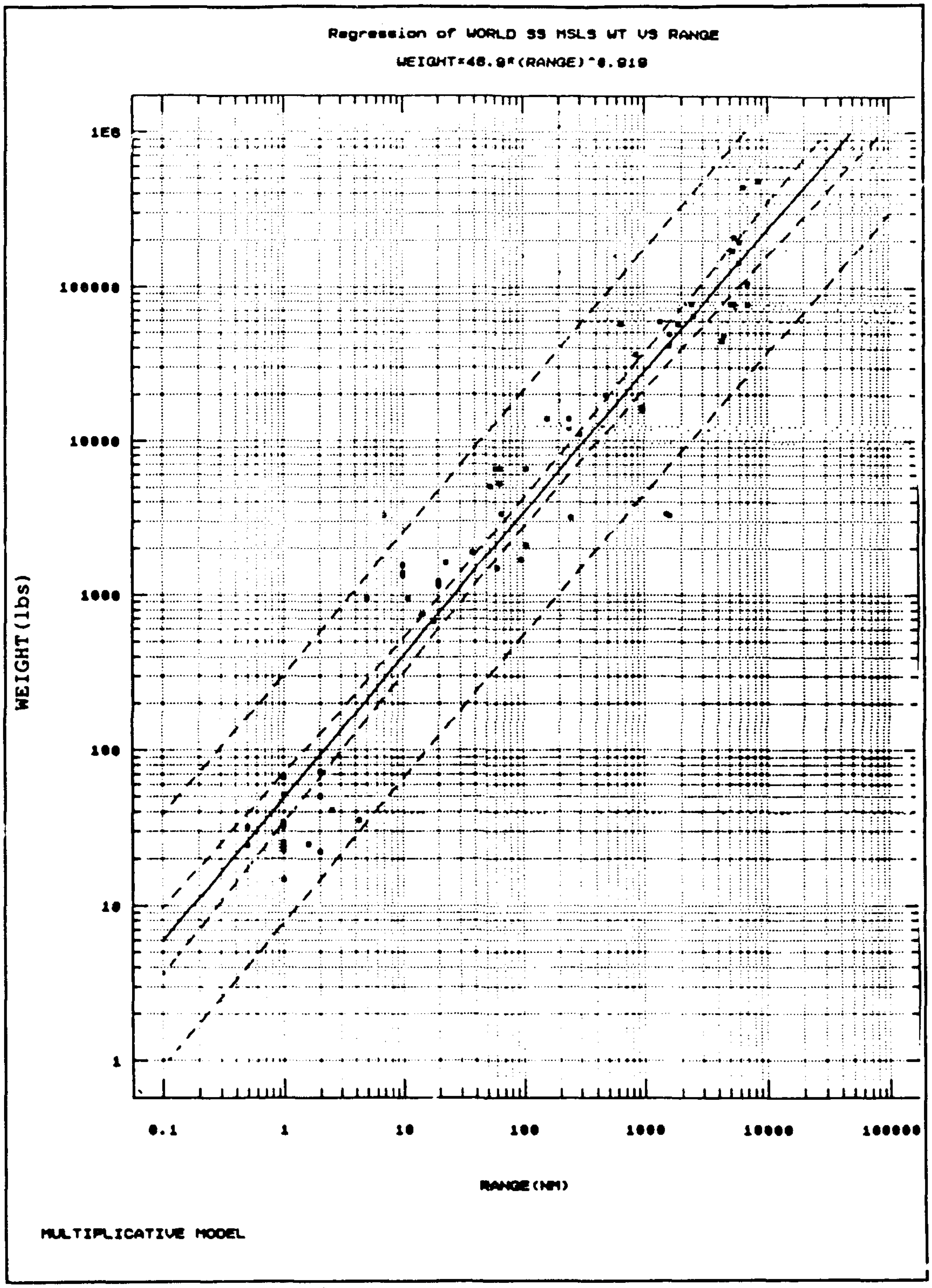

Figure B-14: SSM Weight vs Range

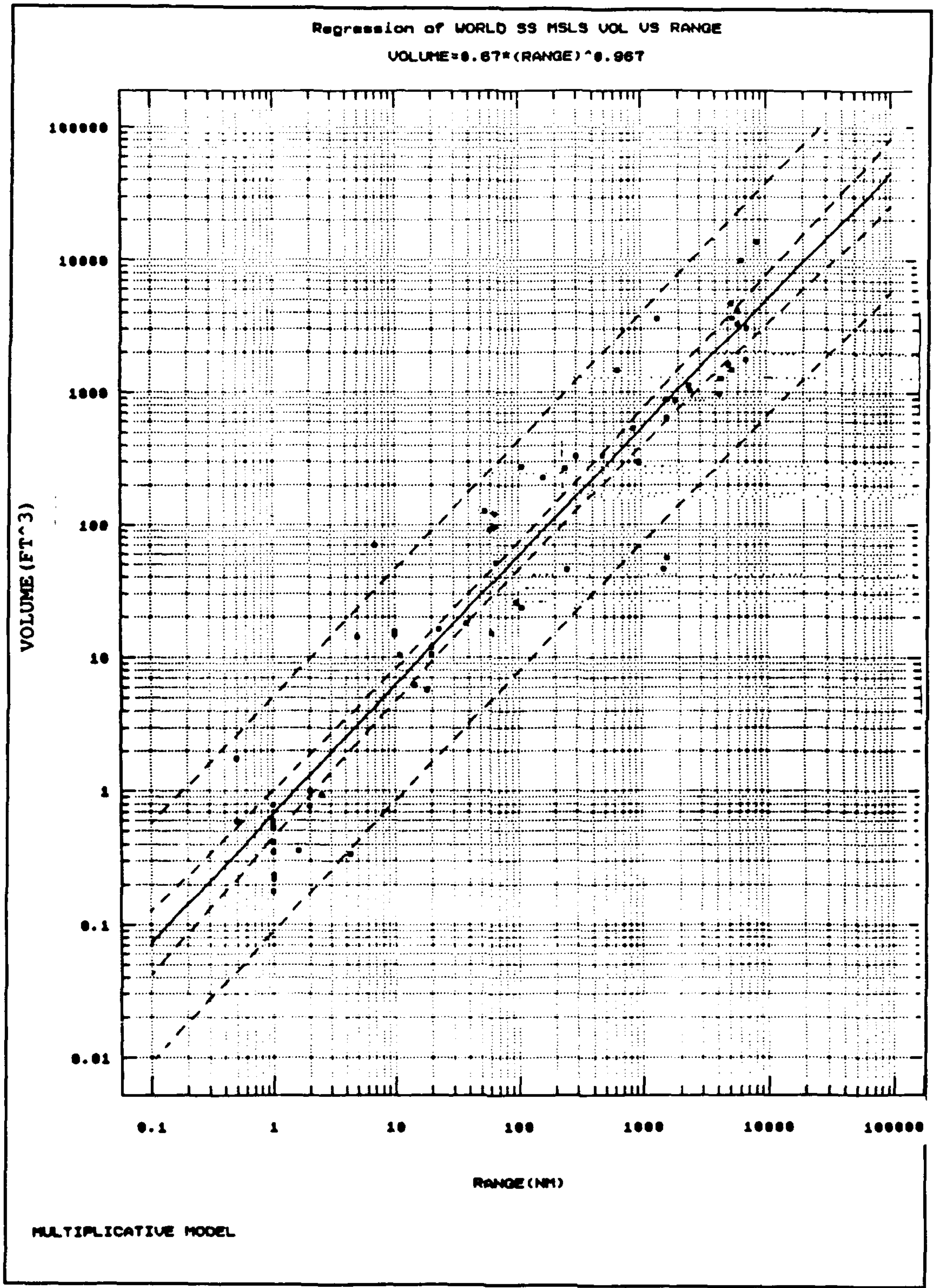

Figure B-15: SSM Volume vs Range

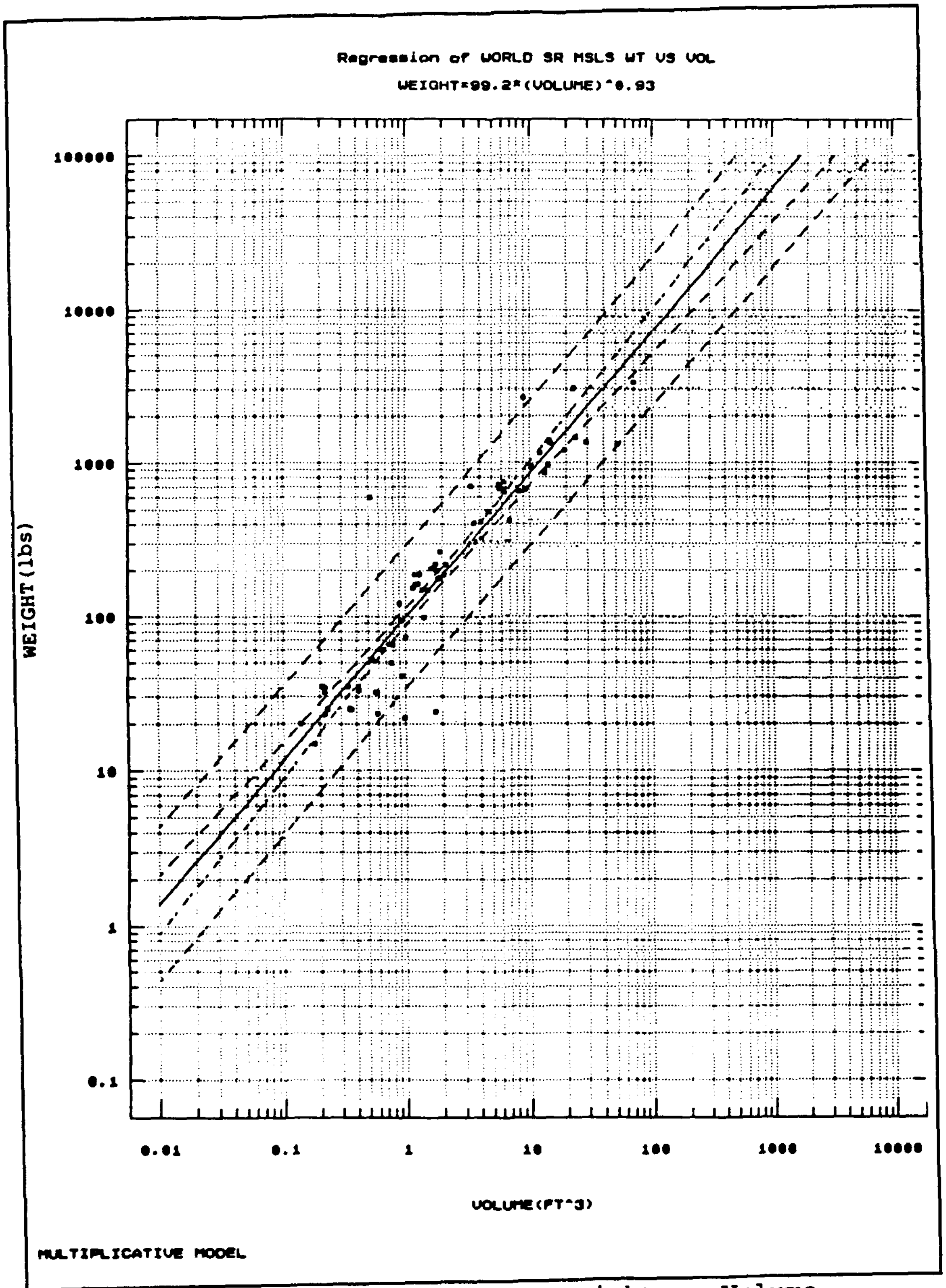

Figure B-16: Short Range Missile Weight vs Volume

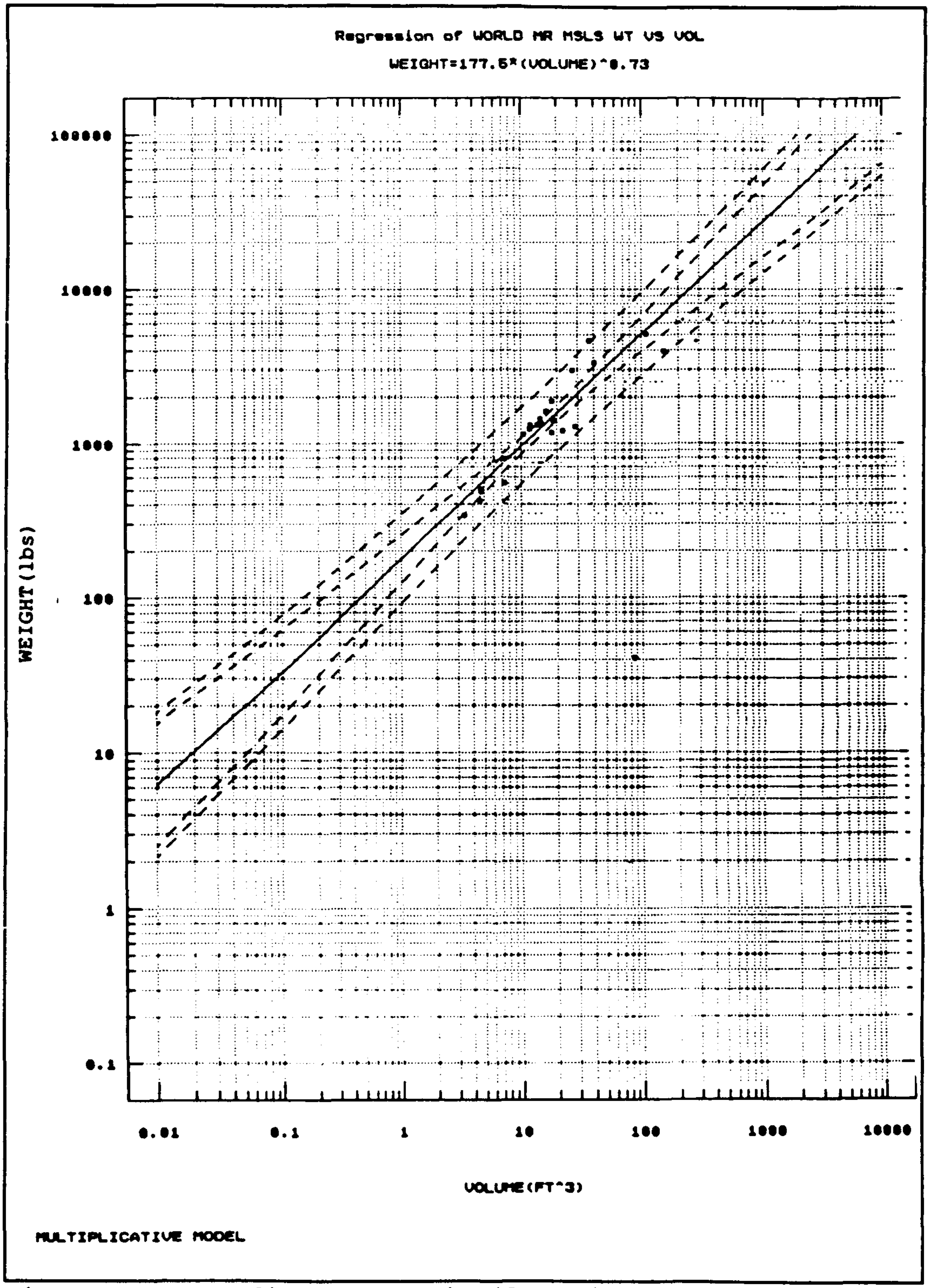

Figure B-17: Medium Range Missile Weight vs Volume

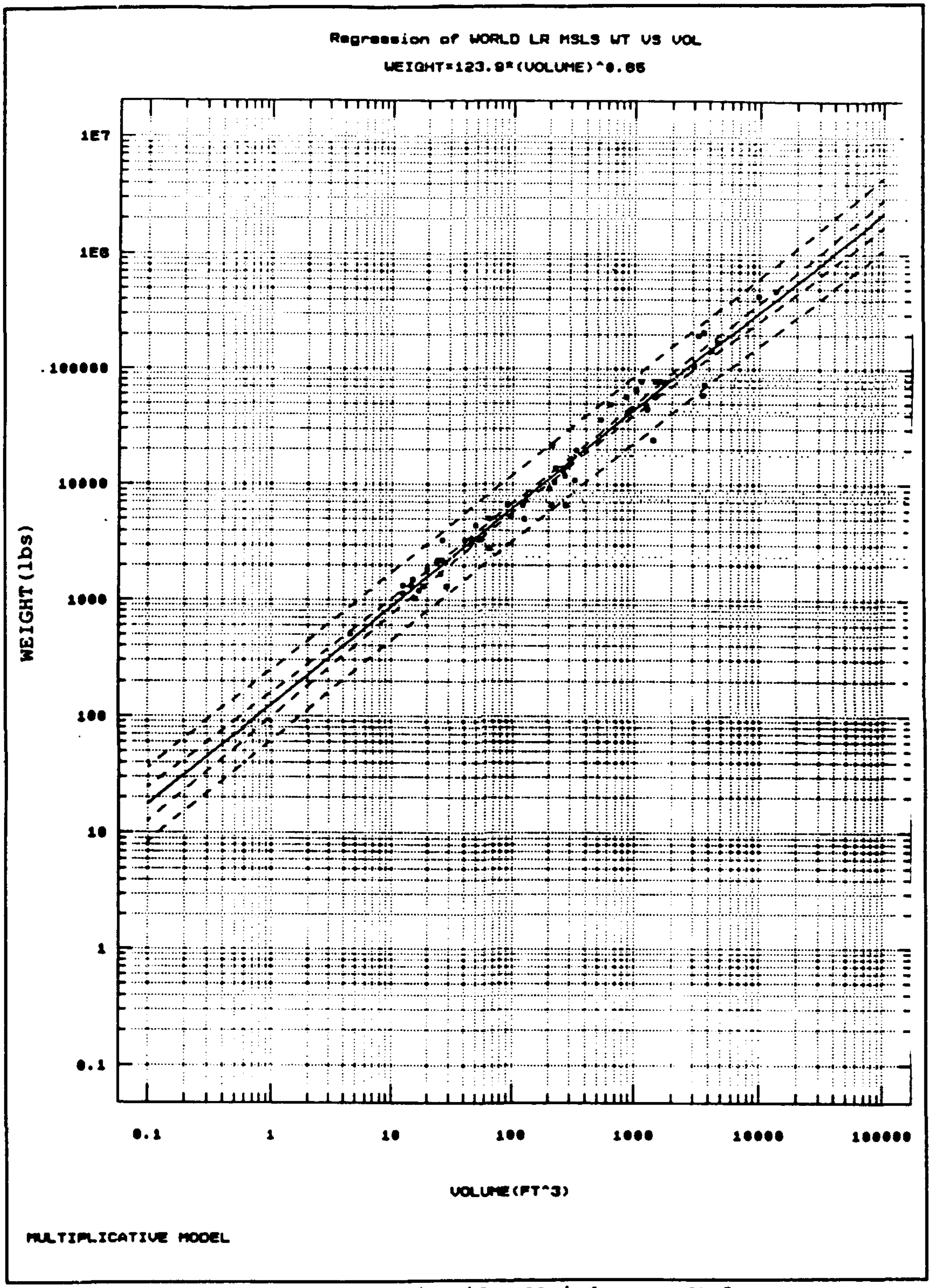

Figure B-18: Long Range Missile Weight vs Volume

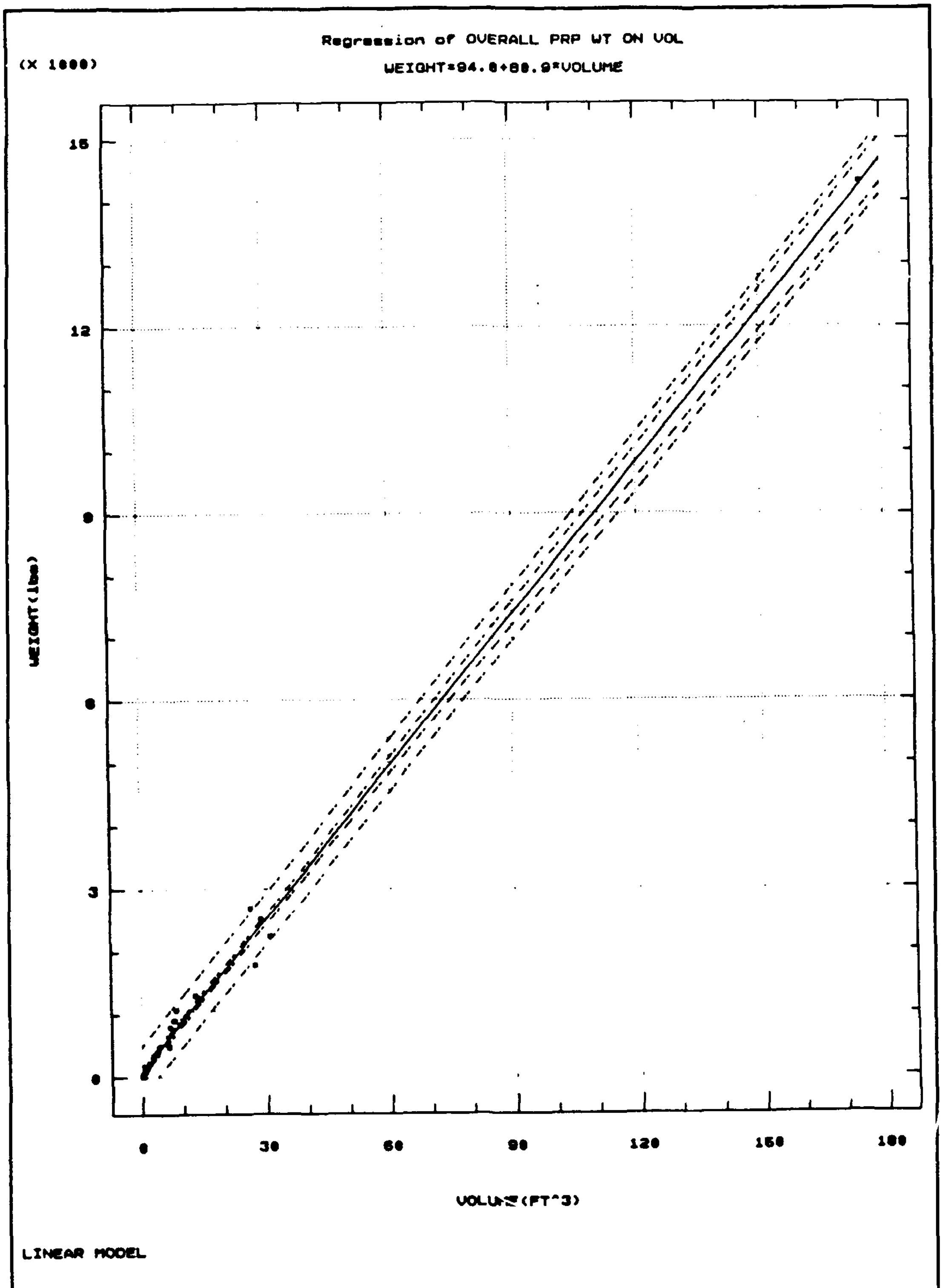

Figure B-19: Overall Propulsion Weight vs Propulsion Volume

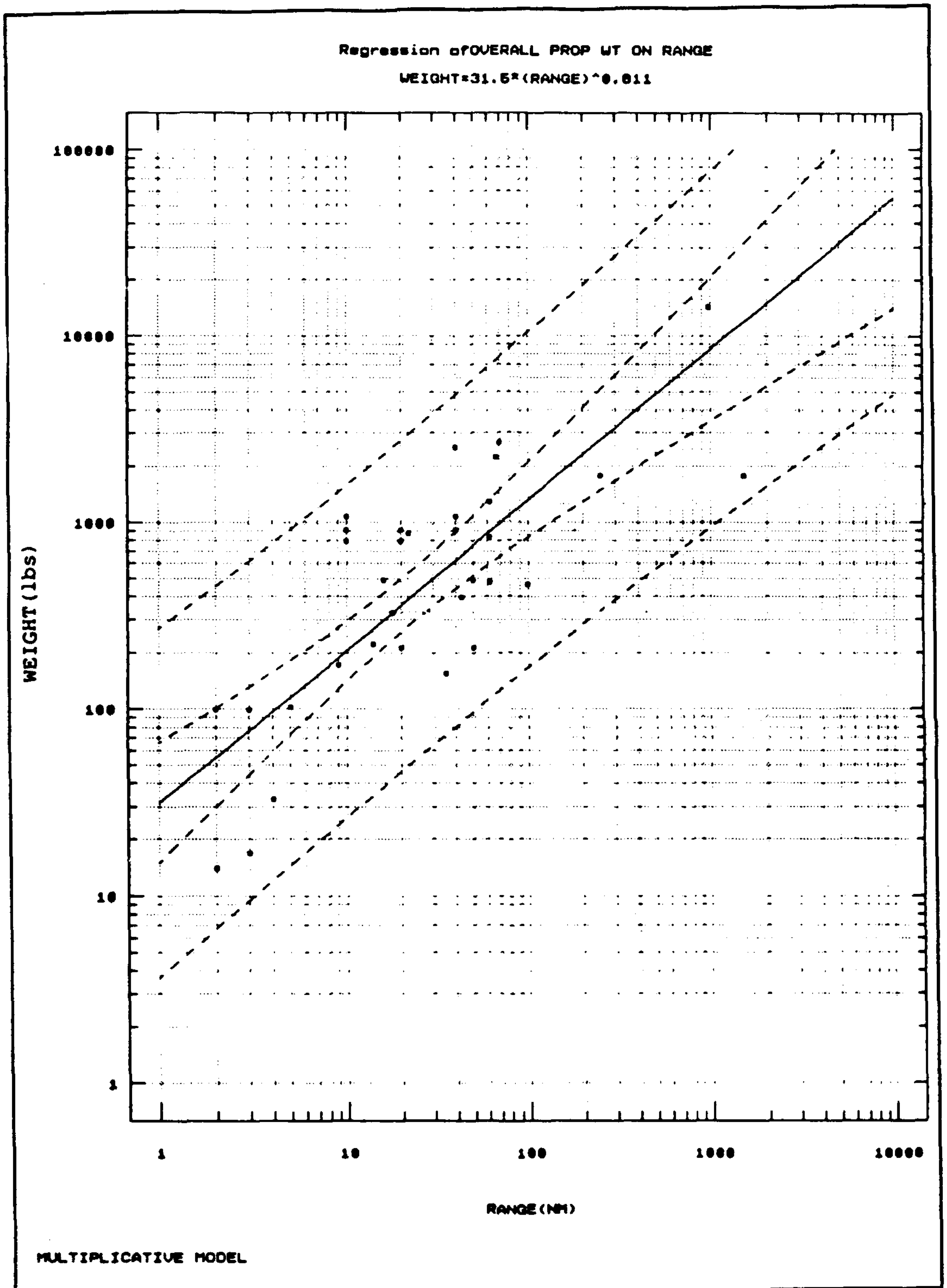

Figure B-20: Overall Propulsion Weight vs Range

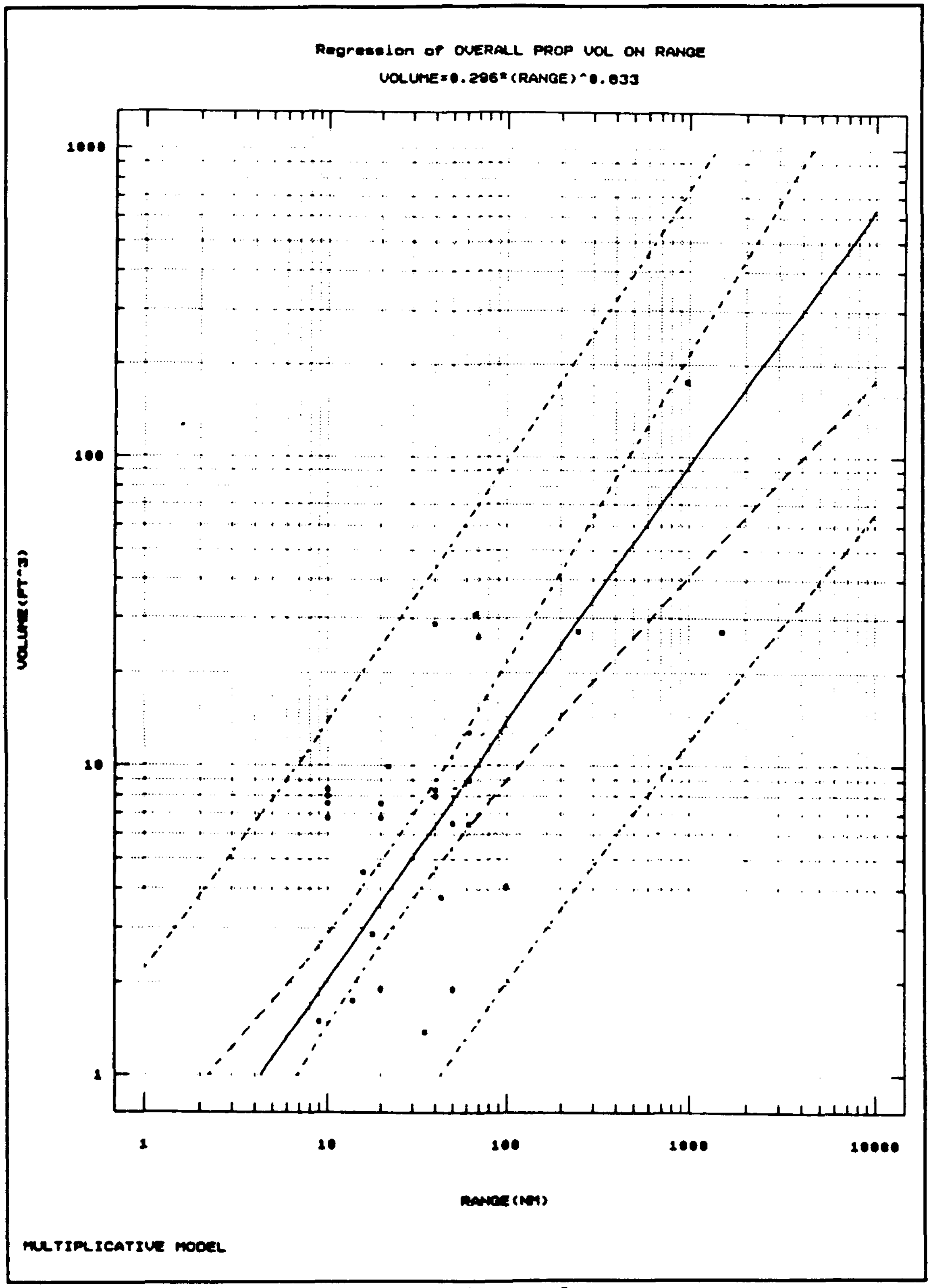

Figure B-21: Overall Propulsion Volume vs Range

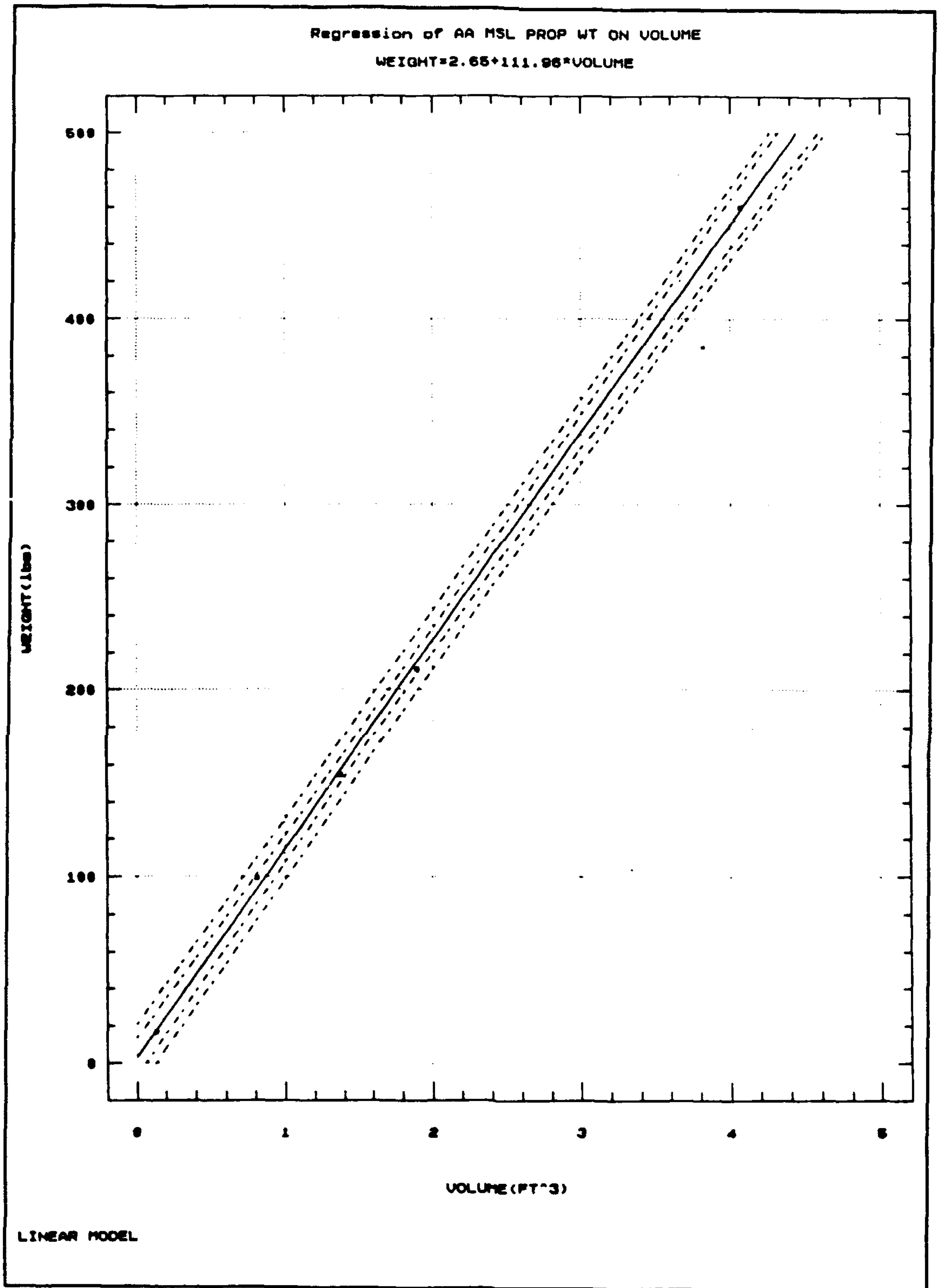

Figure B-22: AAM Propulsion Weight vs Volume

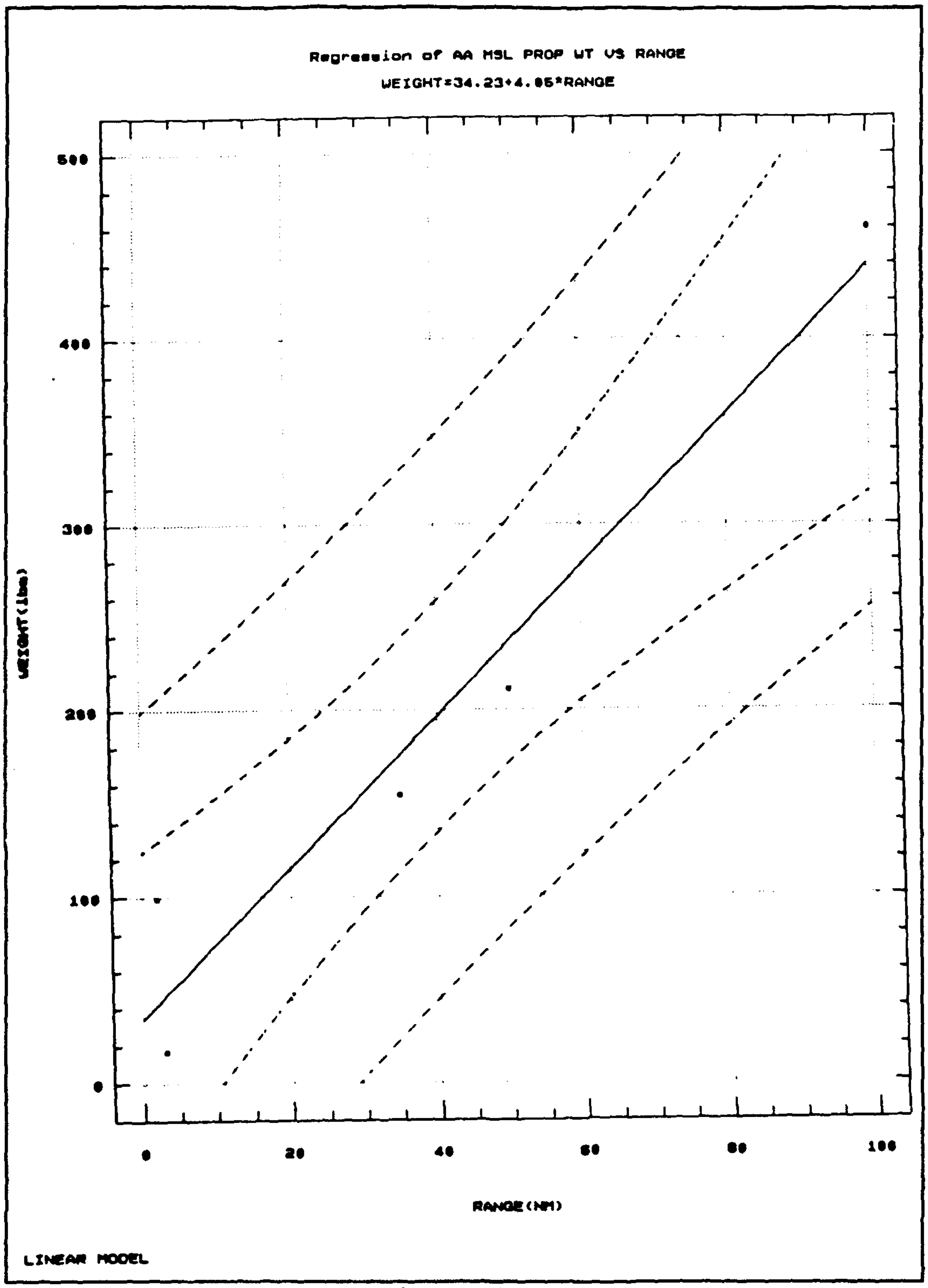

Figure B-23: AAM Propulsion Weight vs Range

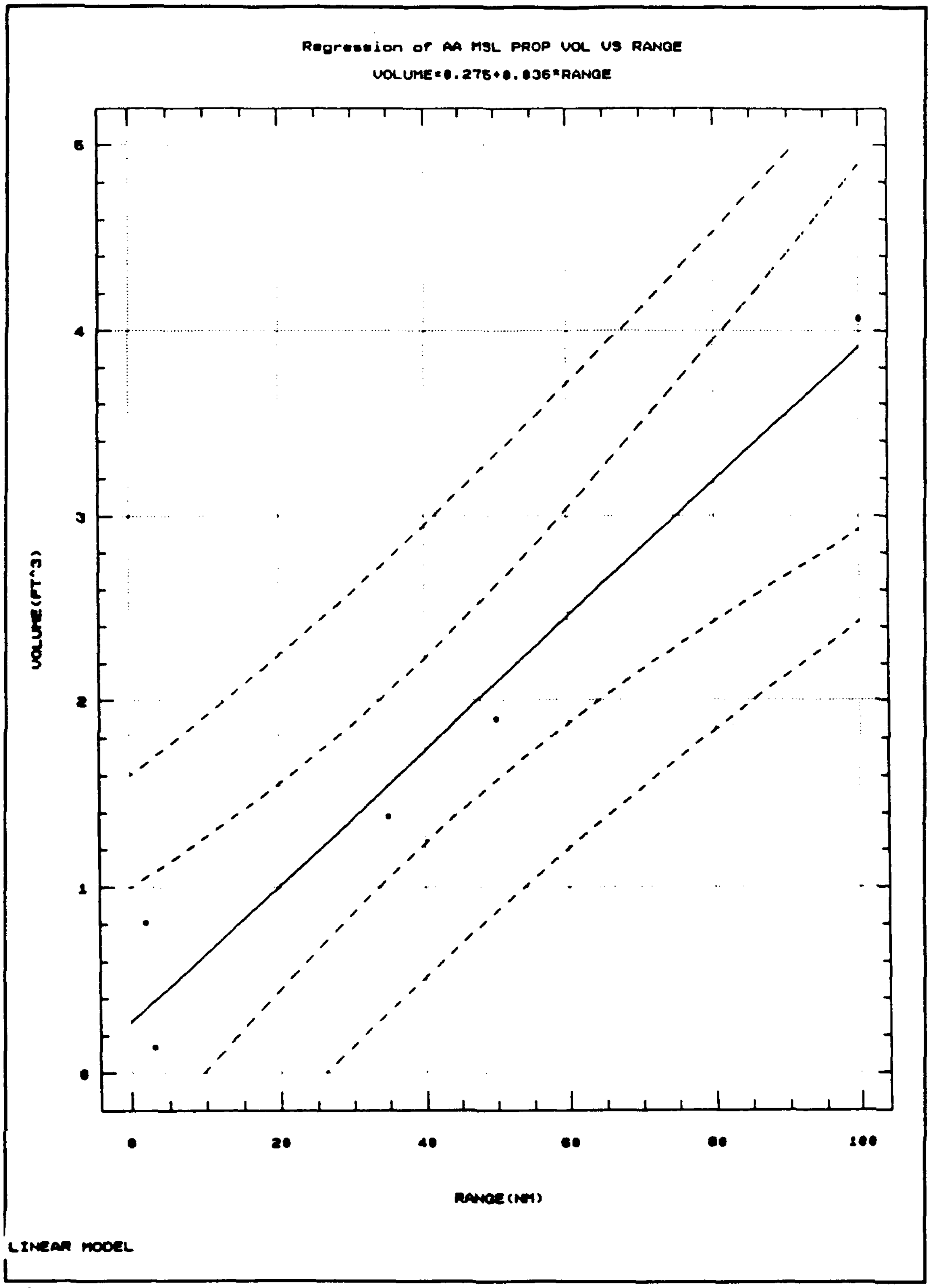

Figure B-24: AAM Propulsion Volume vs Range

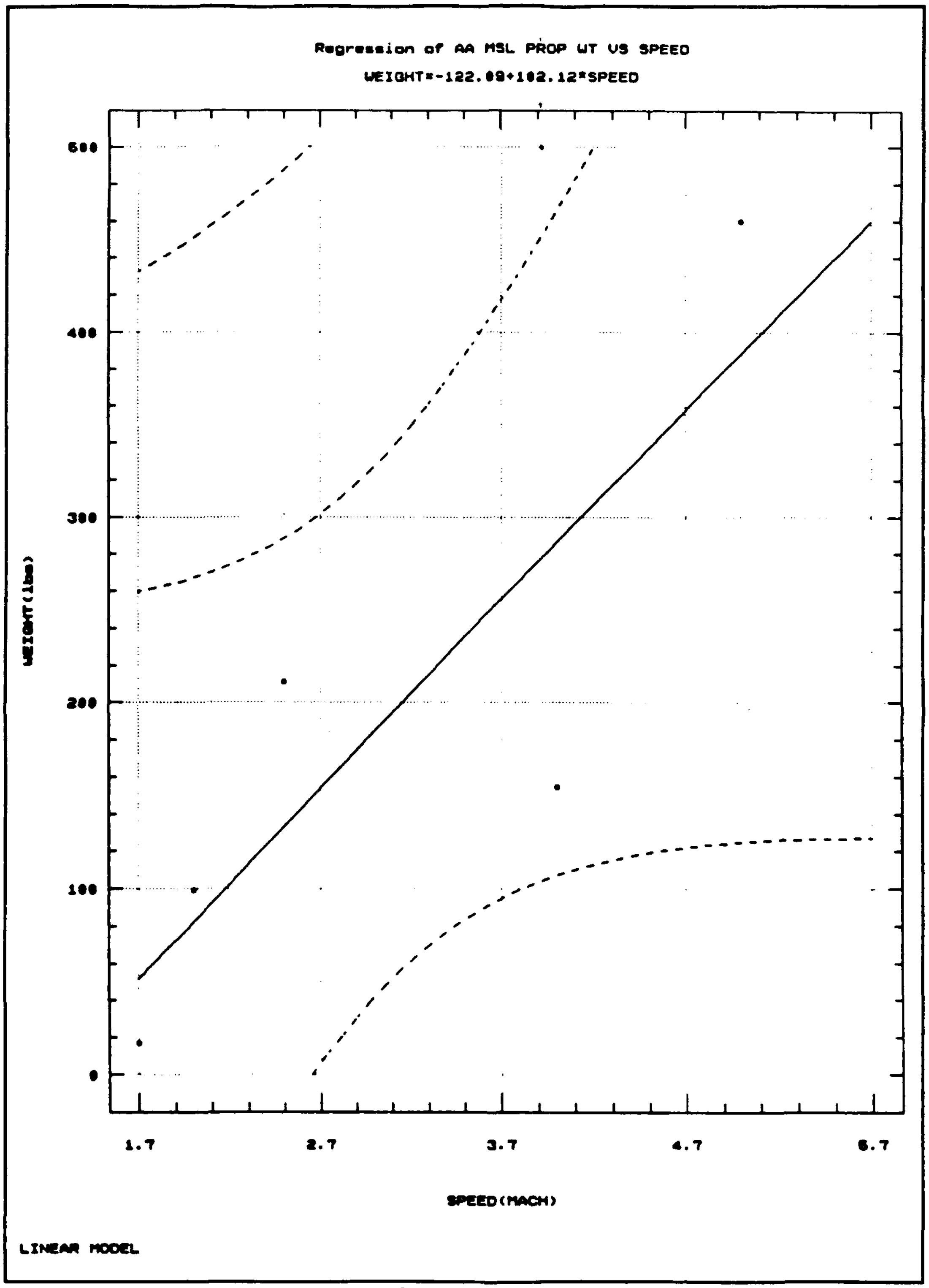

Figure B-25: AAM Propulsion Weight vs Speed

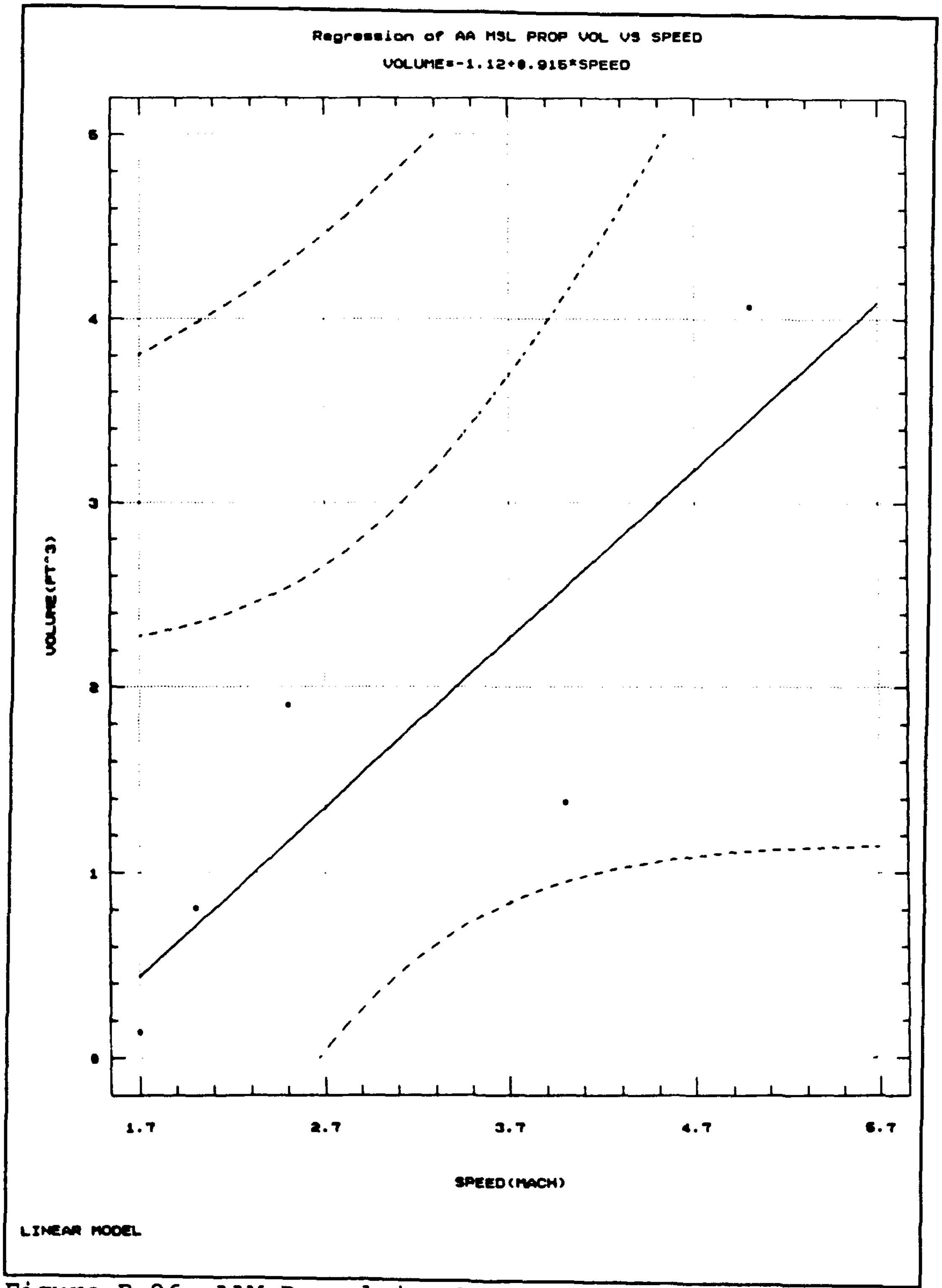

Figure B-26: AAM Propulsion Volume vs Speed

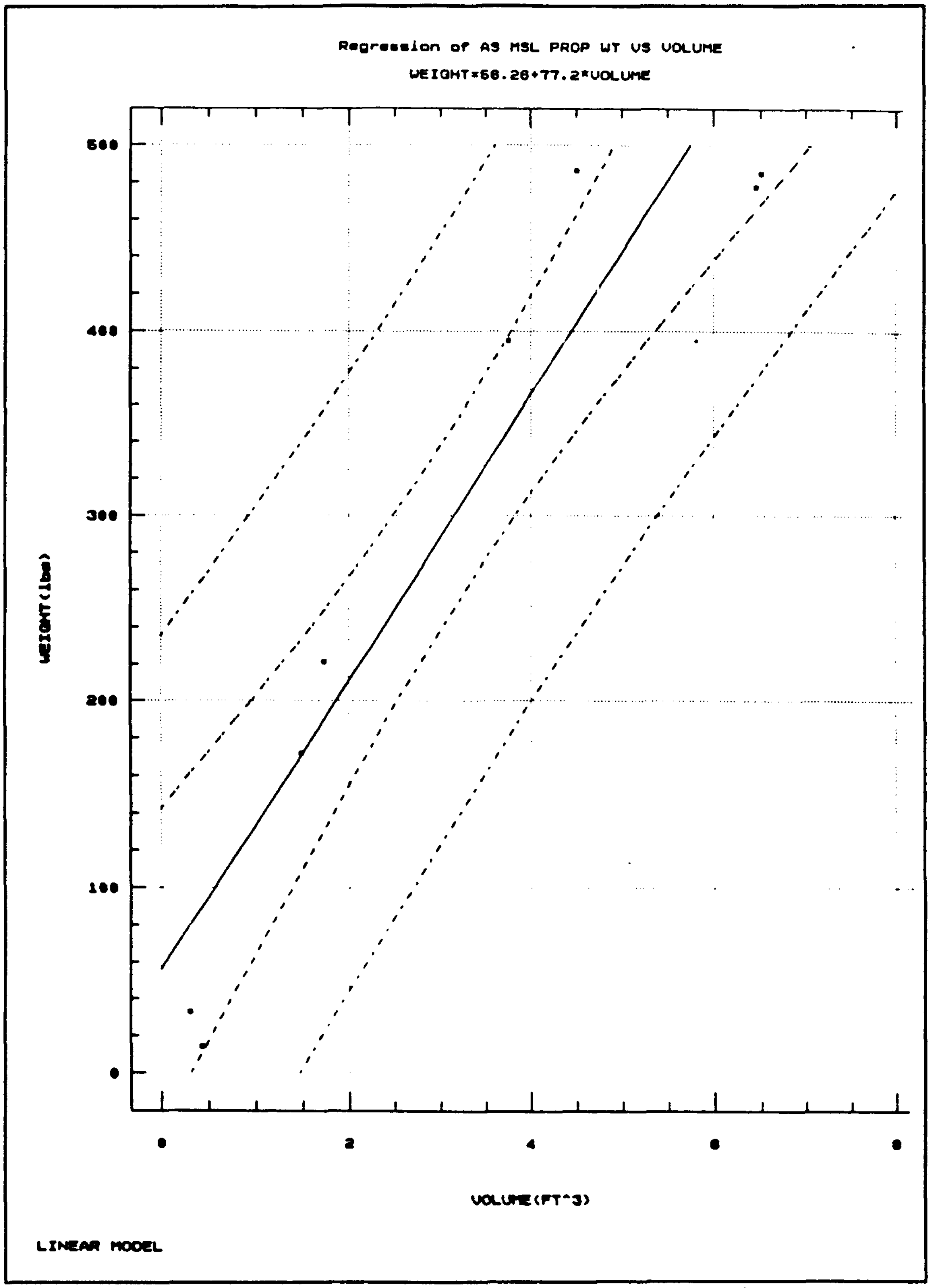

Figure B-27: ASM Propulsion Weight vs Propulsion Volume

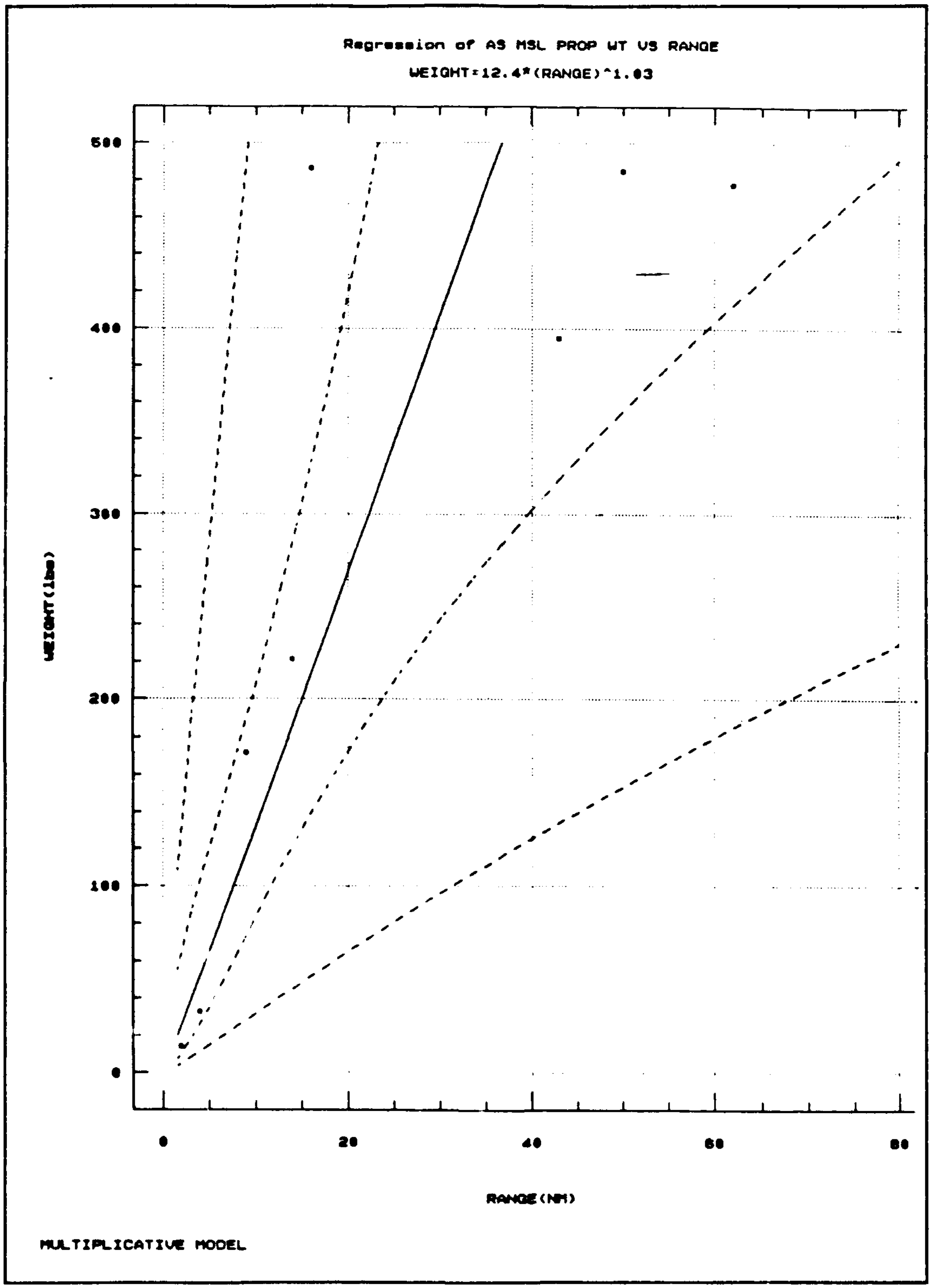

Figure B-28: ASM Propulsion Weight vs Range

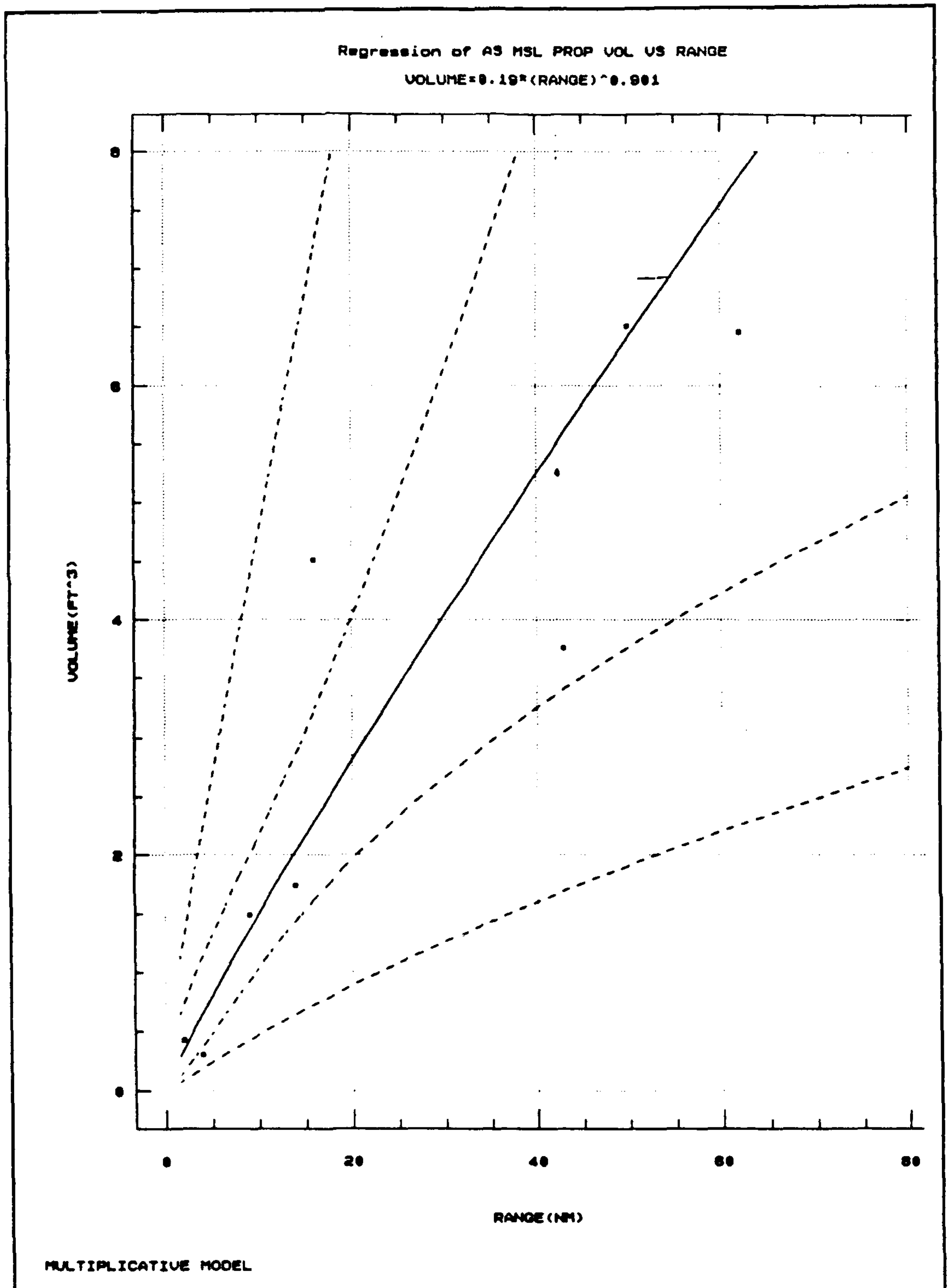

Figure B-29: ASM Propulsion Volume vs Range

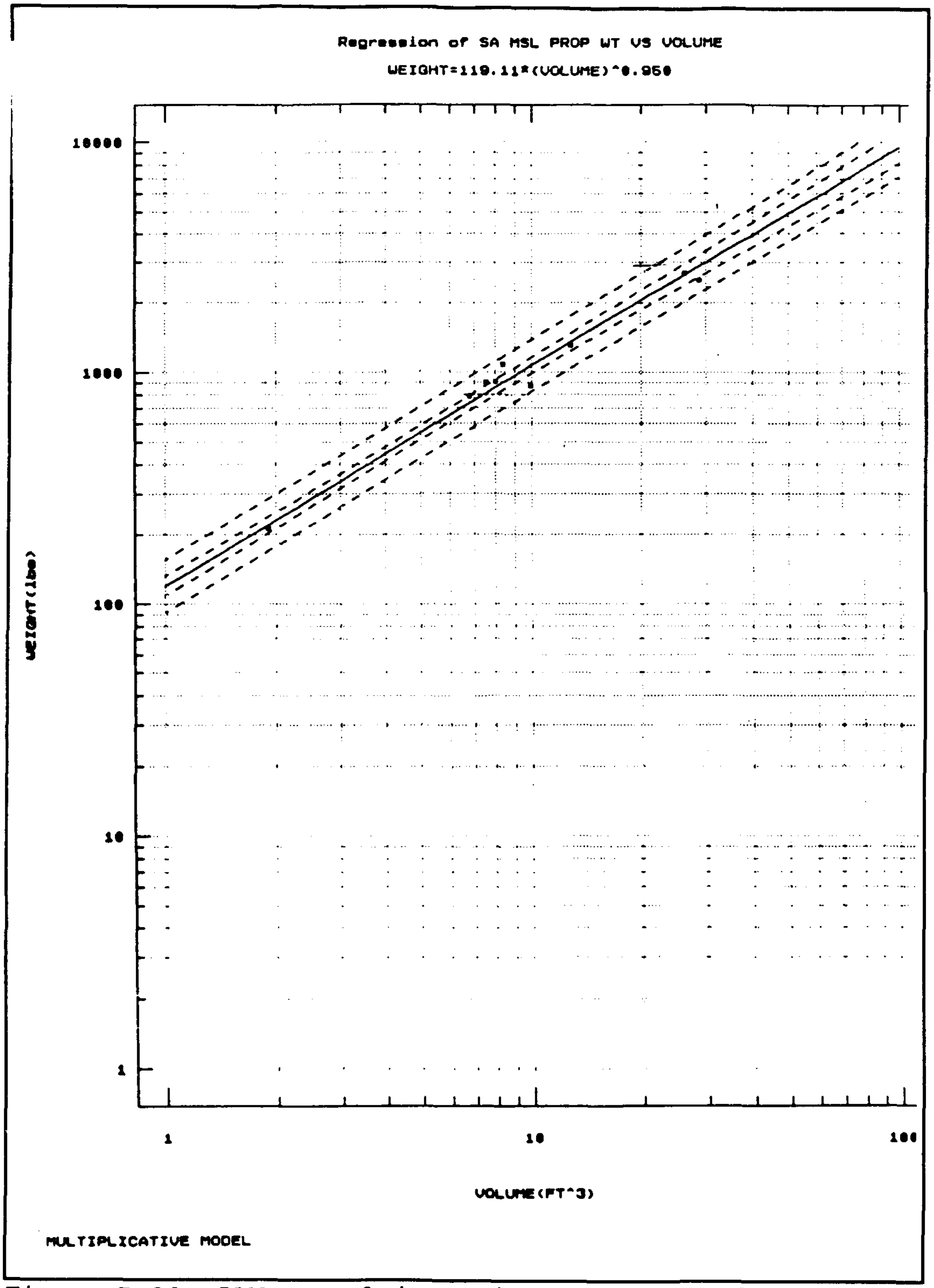

Figure B-30: SAM Propulsion Weight vs Propulsion Volume

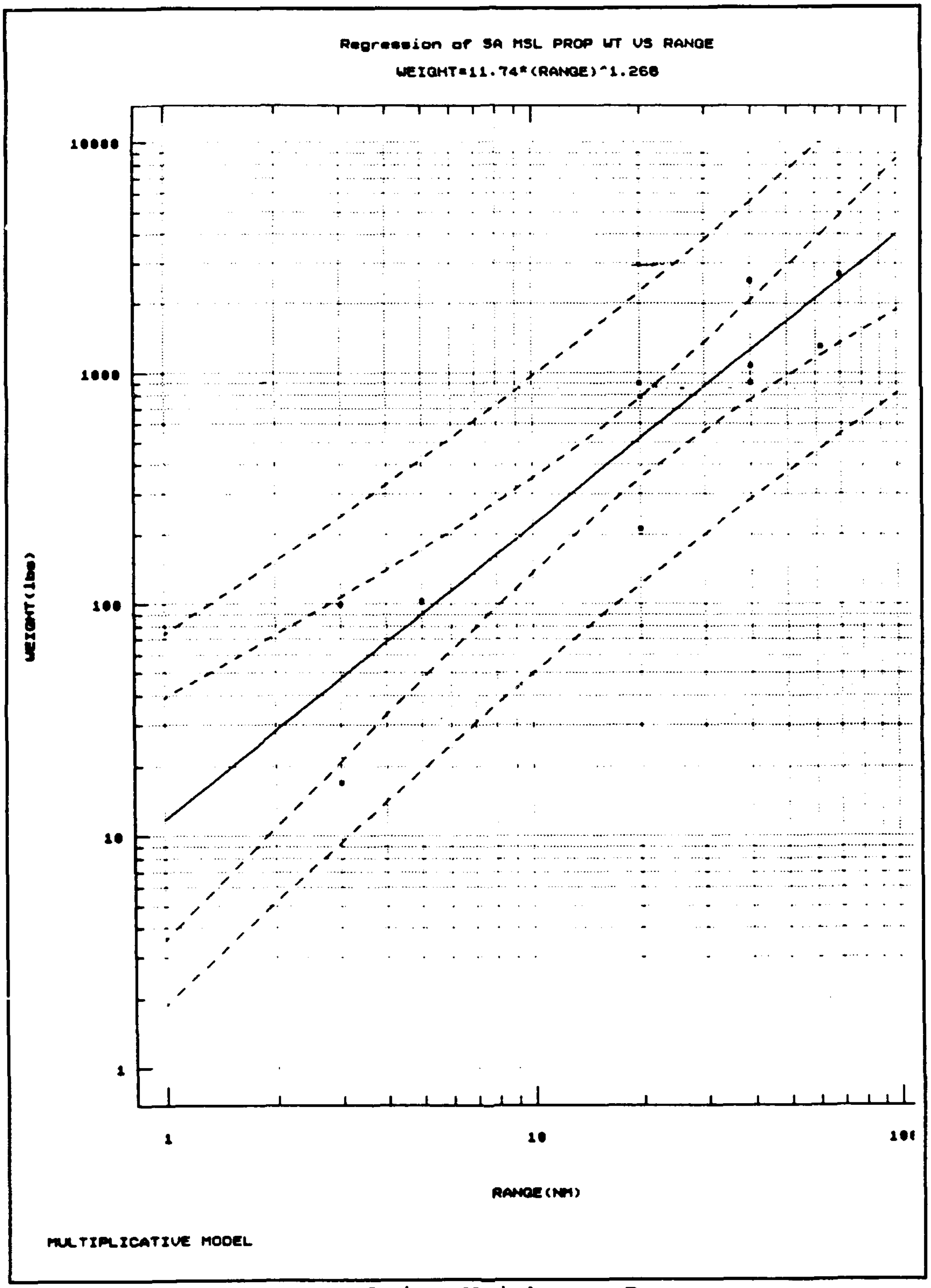

Figure B-31: SAM Propulsion Weight vs Range

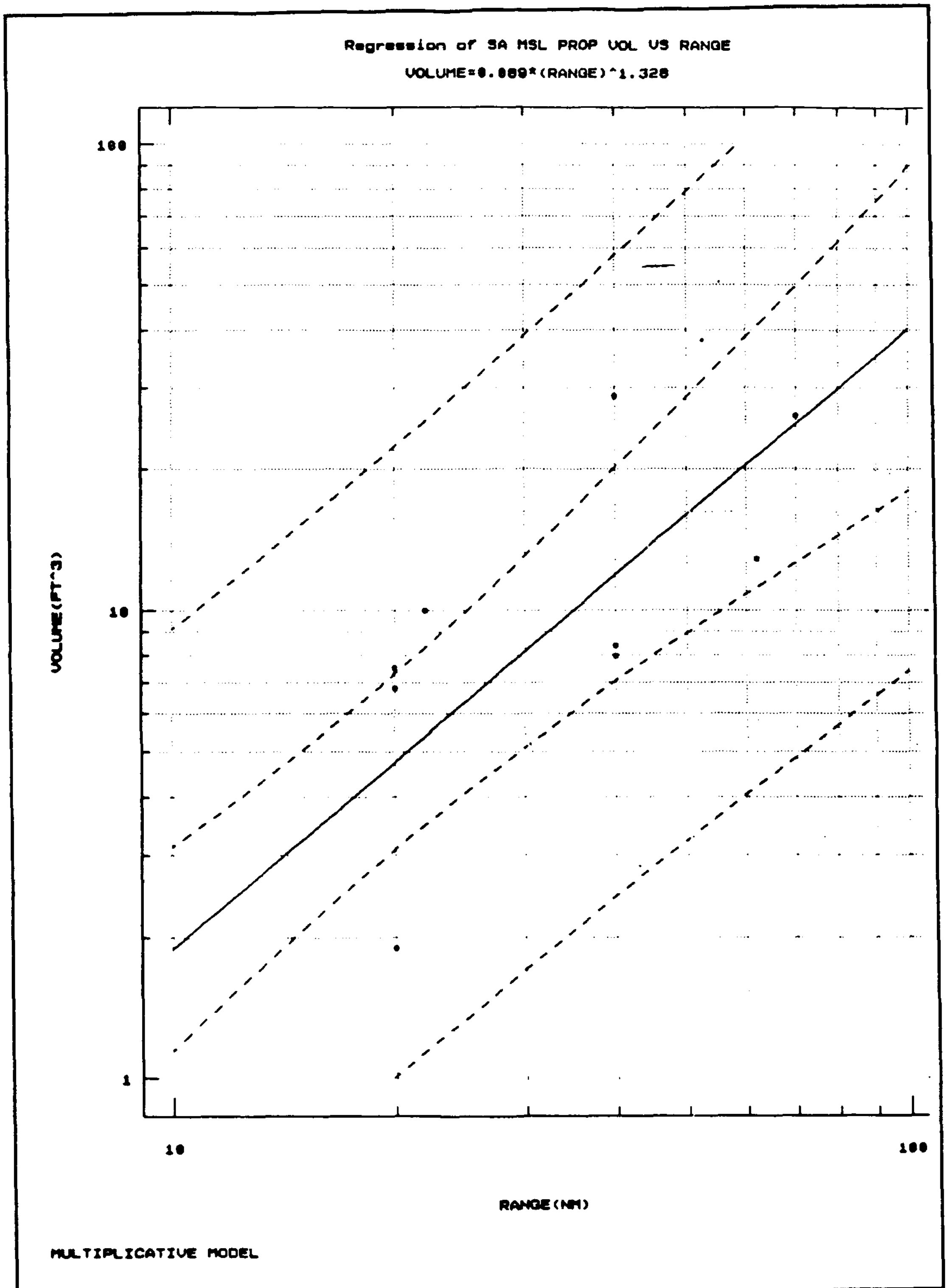

Figure B-32: SAM Propulsion Volume vs Range

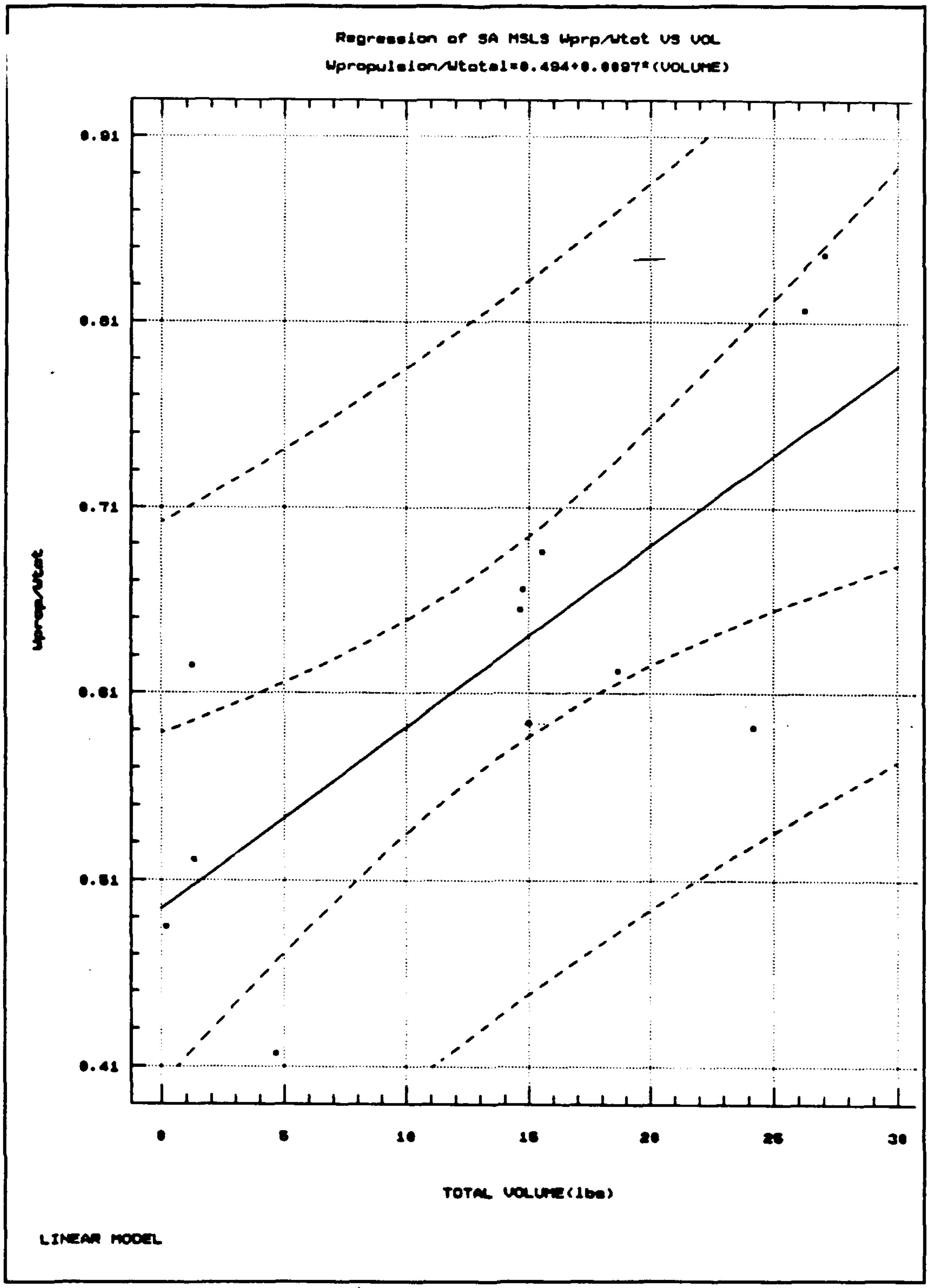

Figure B-33: SAM Wprp/Wt vs Volume

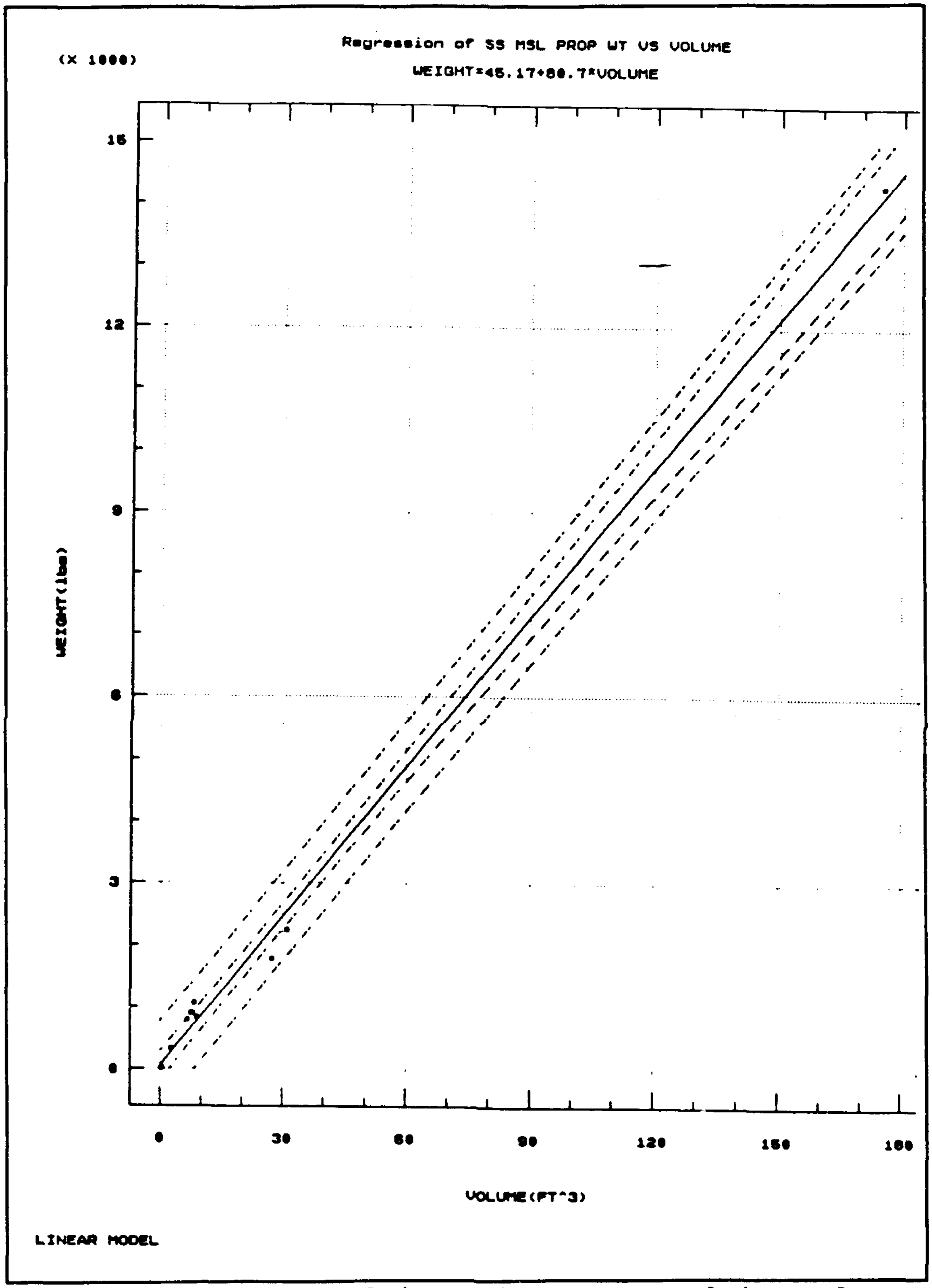

Figure B-34: SSM Propulsion Weight vs Propulsion Volume

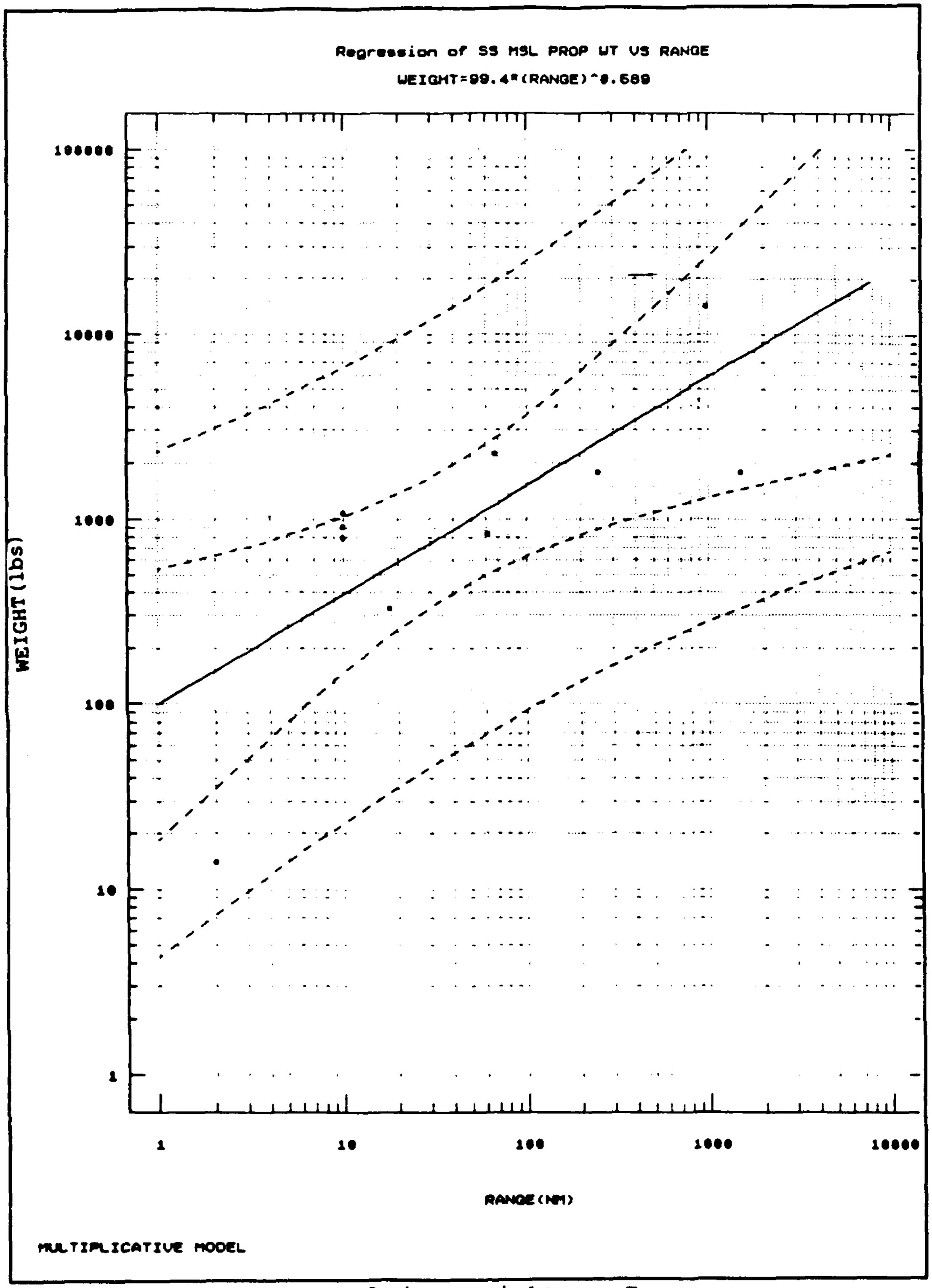

Figure B-35: SSM Propulsion Weight vs Range

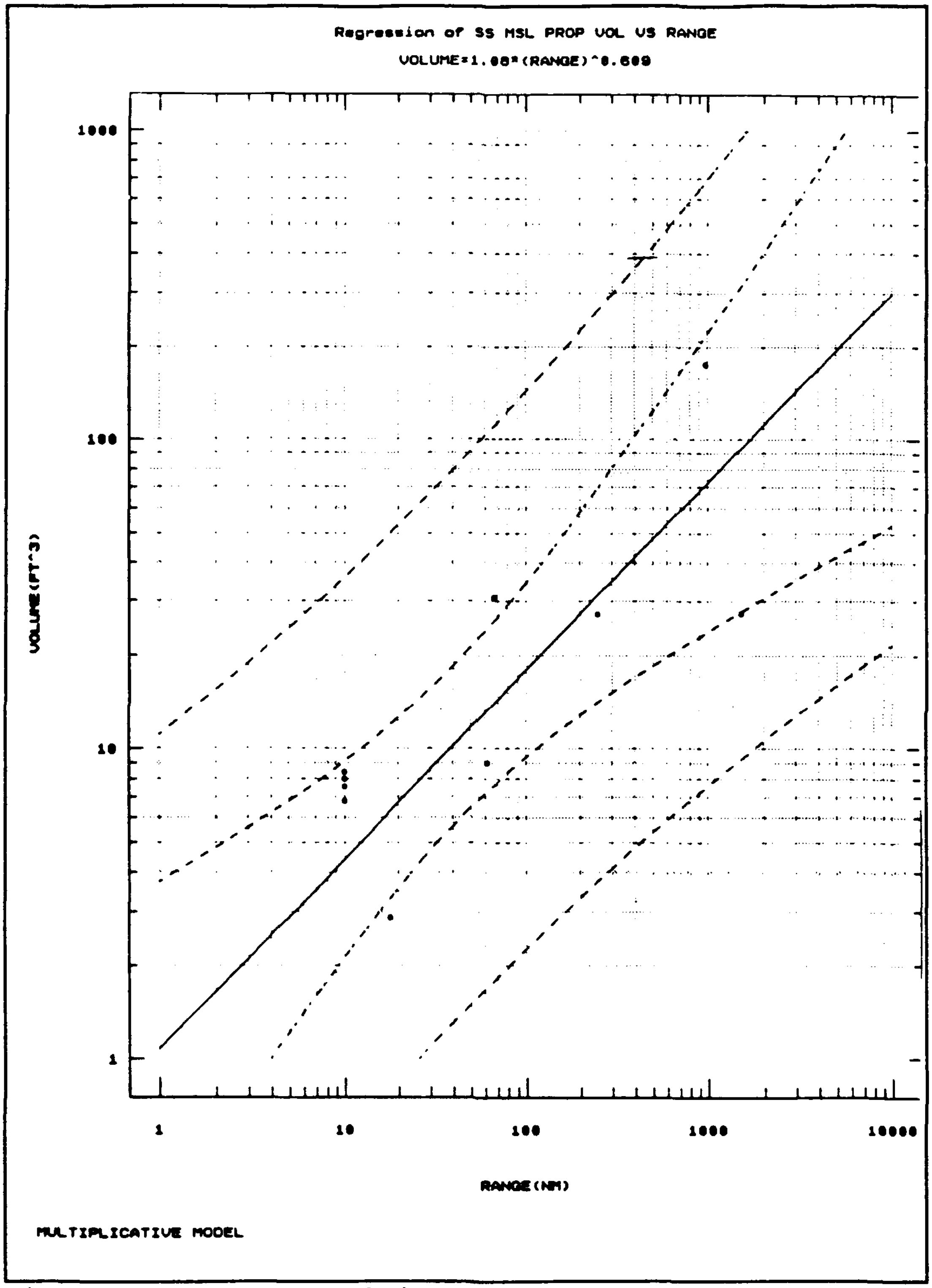

Figure B-36: SSM Propulsion Volume vs Range

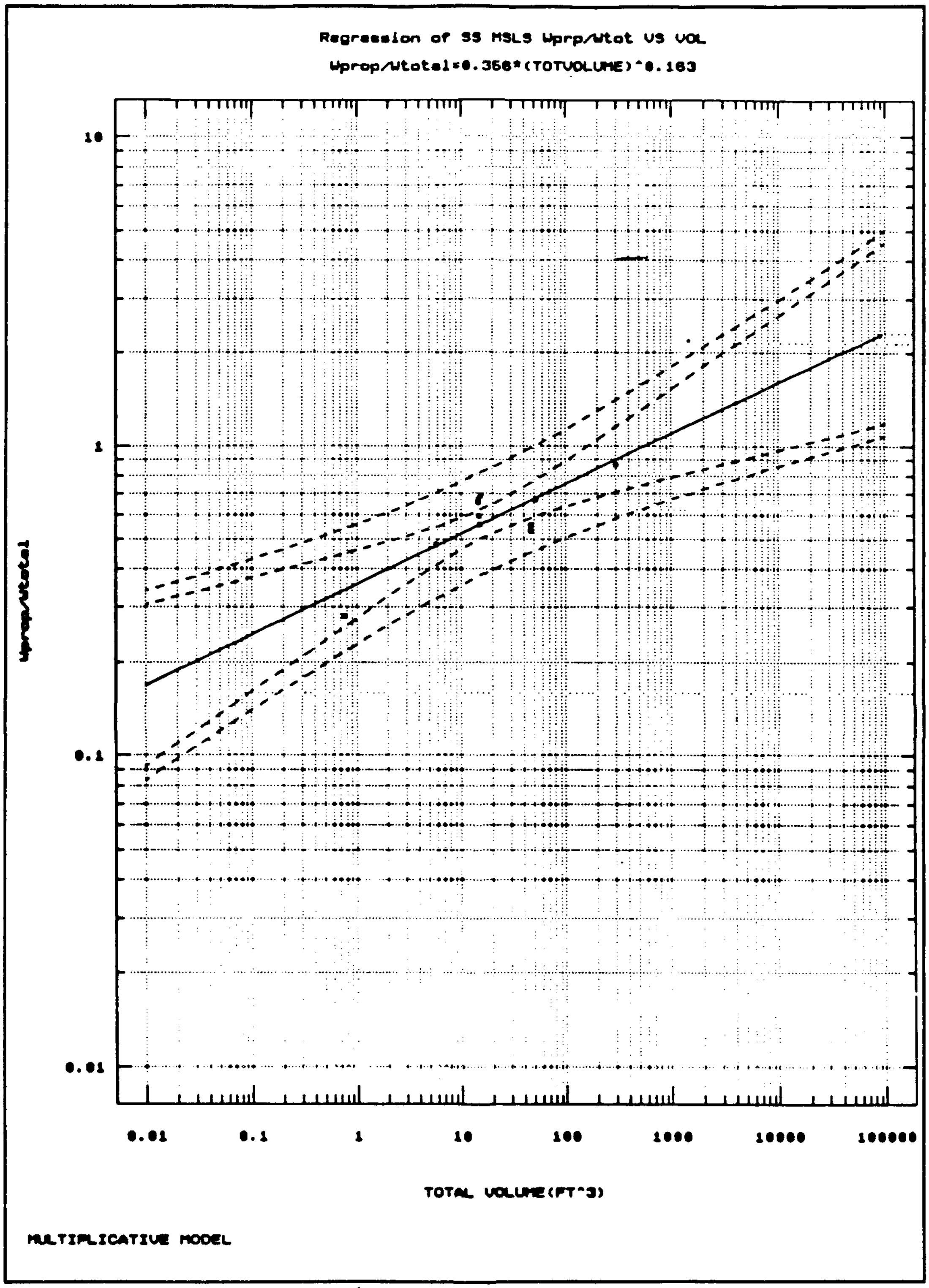

Figure B-37: SSM Wprp/Wt vs Volume

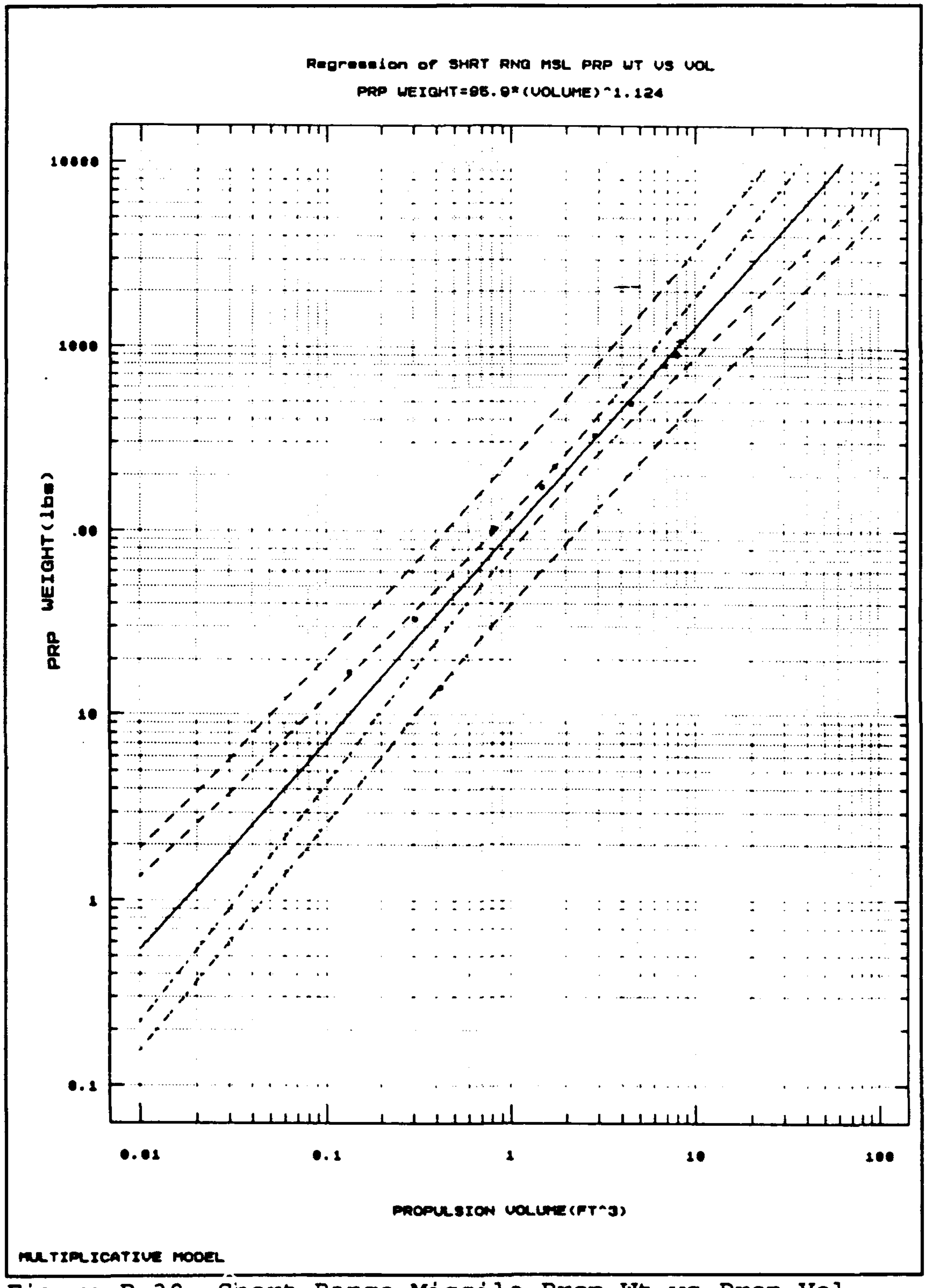

Figure B-38: Short Range Missile Prop Wt vs Prop Vol

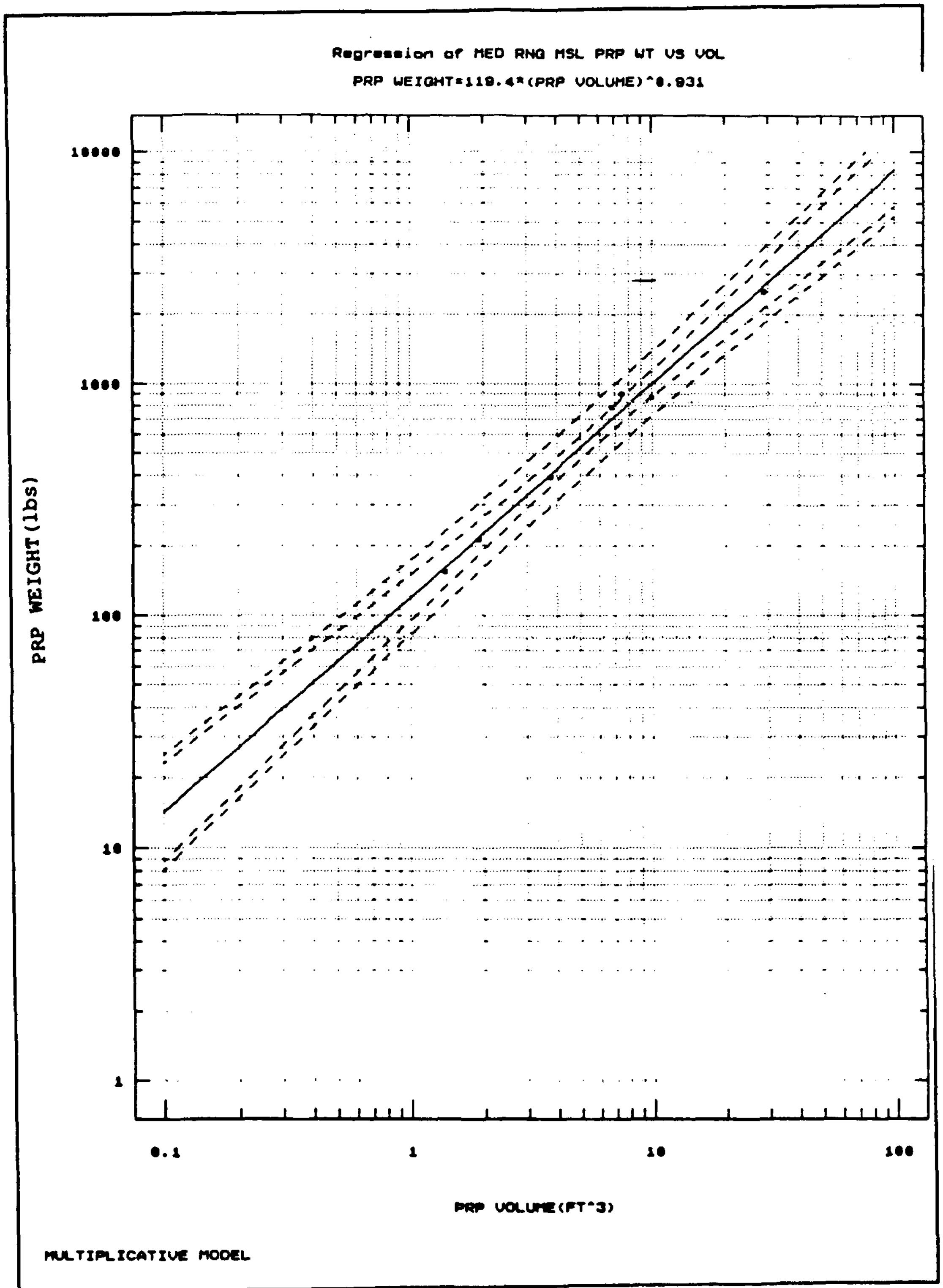

Figure B-39: Medium Range Missile Prop Wt vs Prop Vol

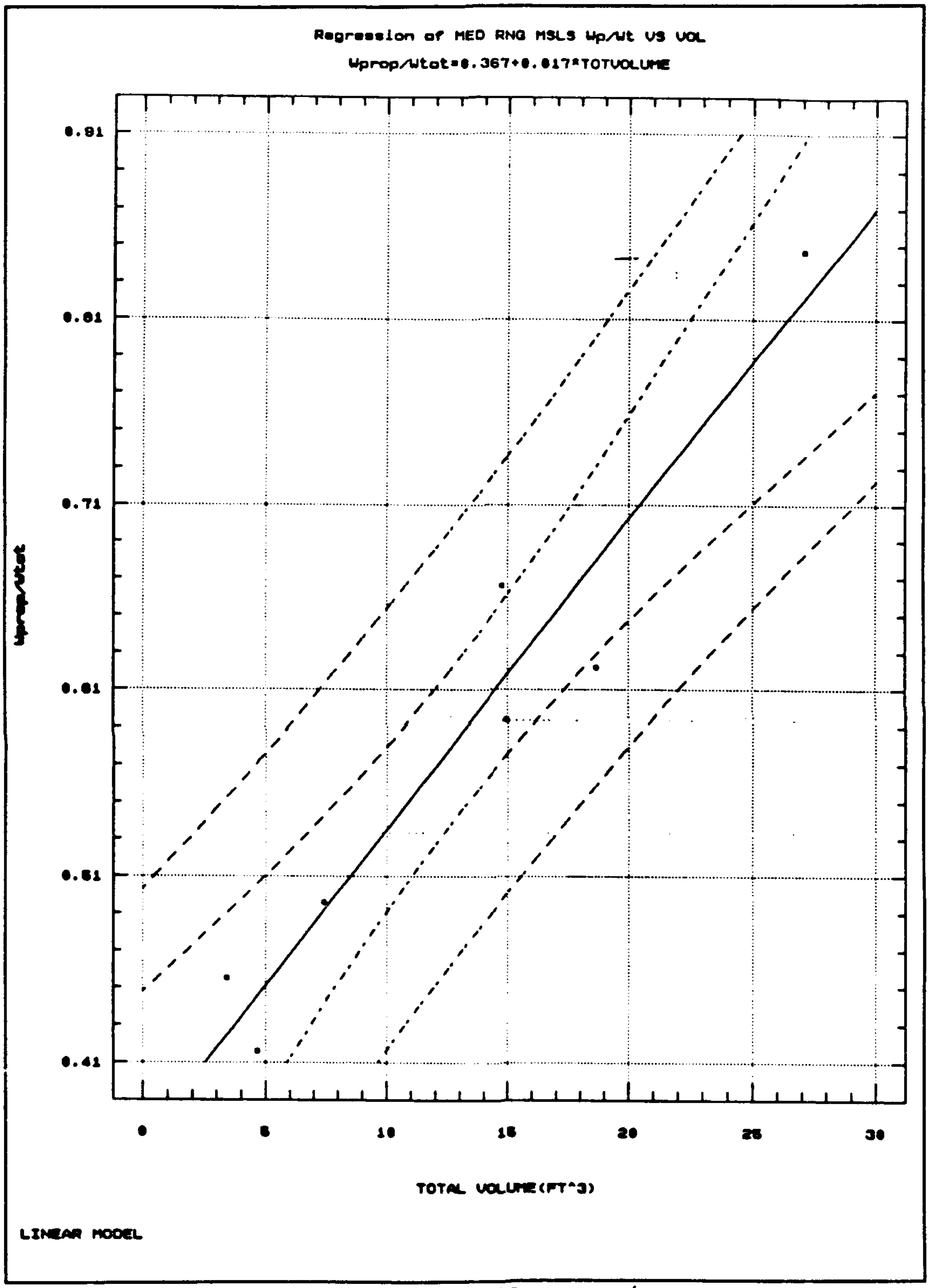

Figure B-40: Medium Range Missile Wprp/Wt vs Volume

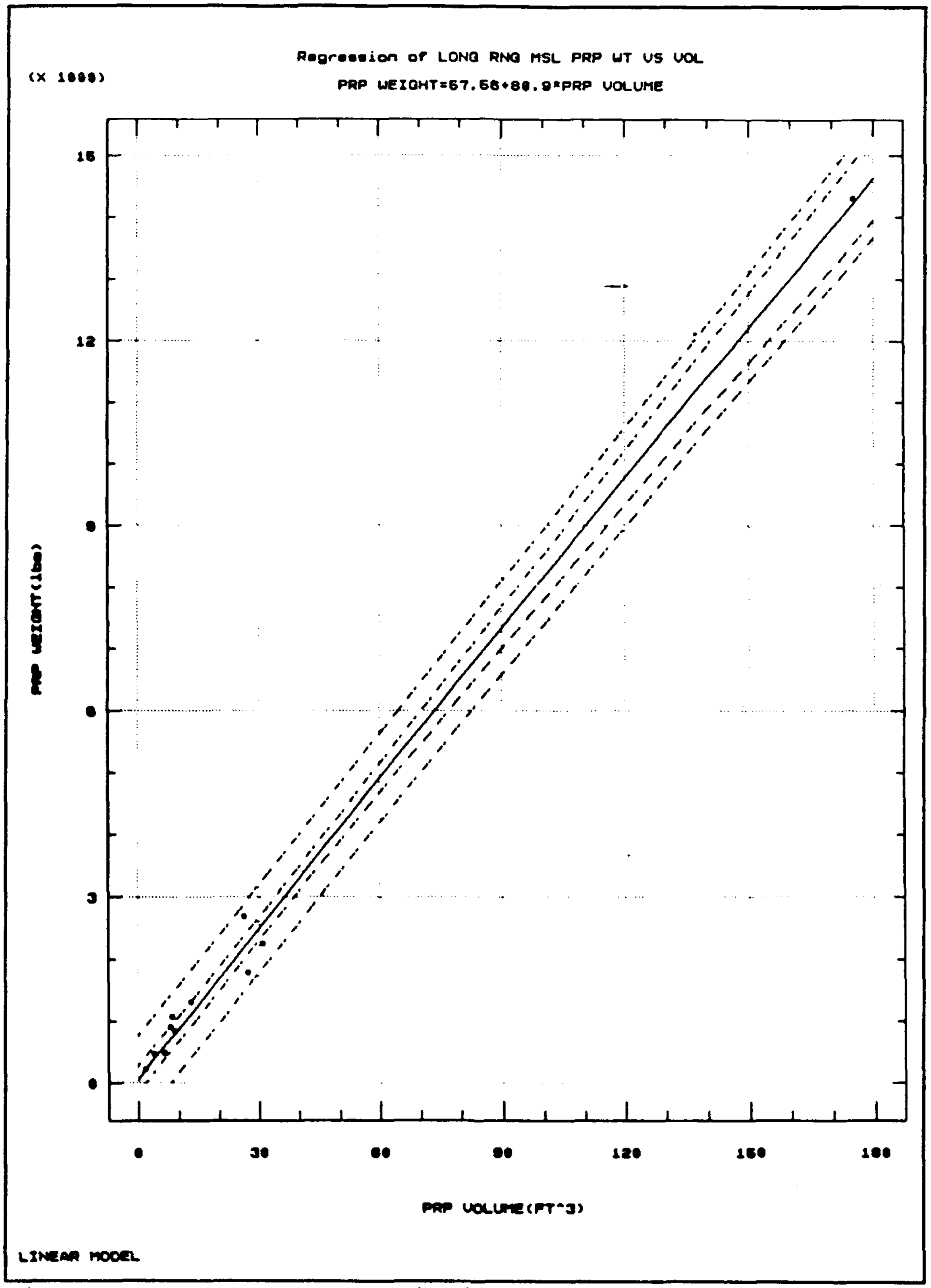

Figure B-41: Long Range Missile Prop Wt vs Prop Vol

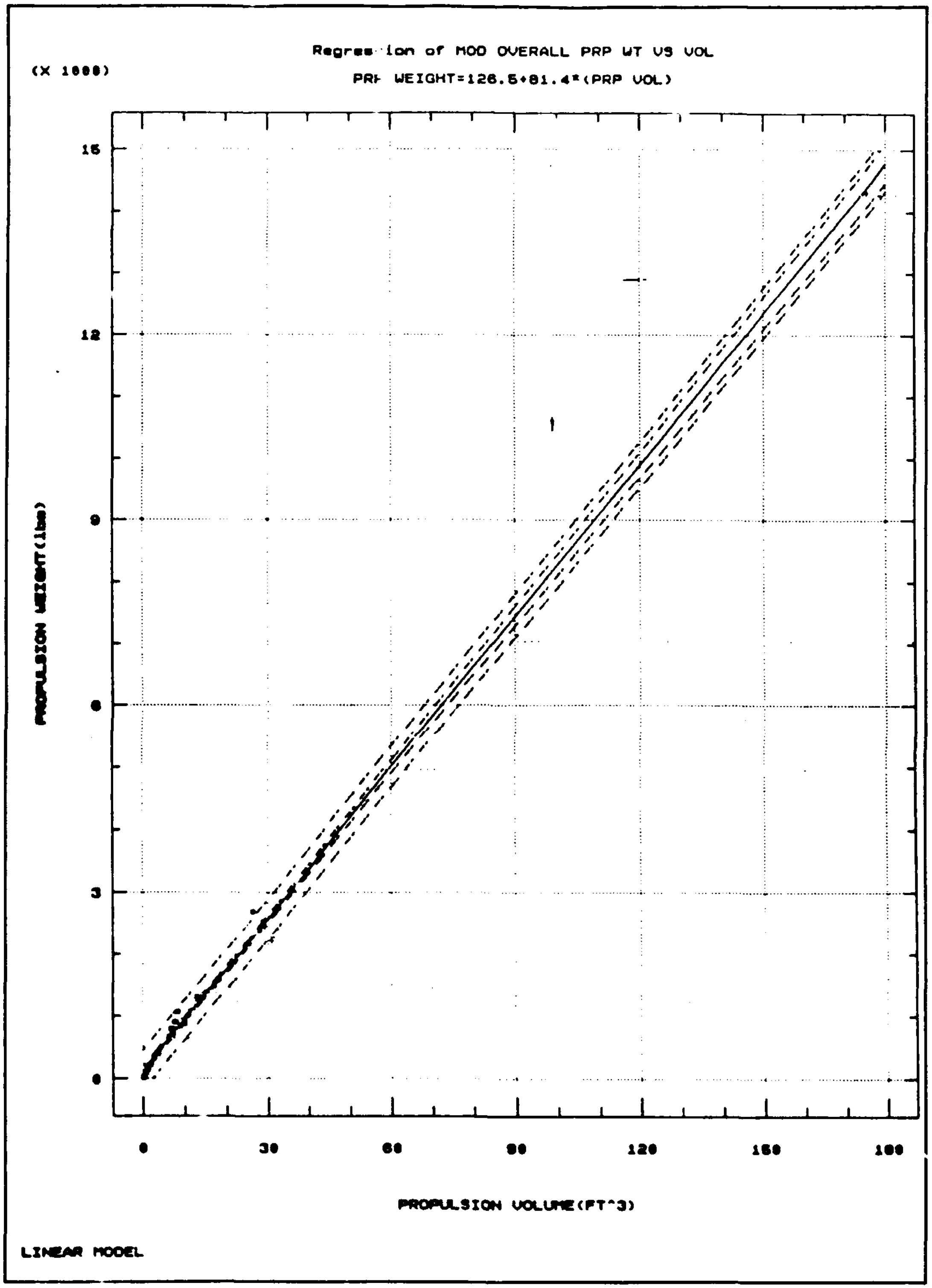

Figure B-42: Overall Rocket Prop Only Prop Wt vs Prop Vol

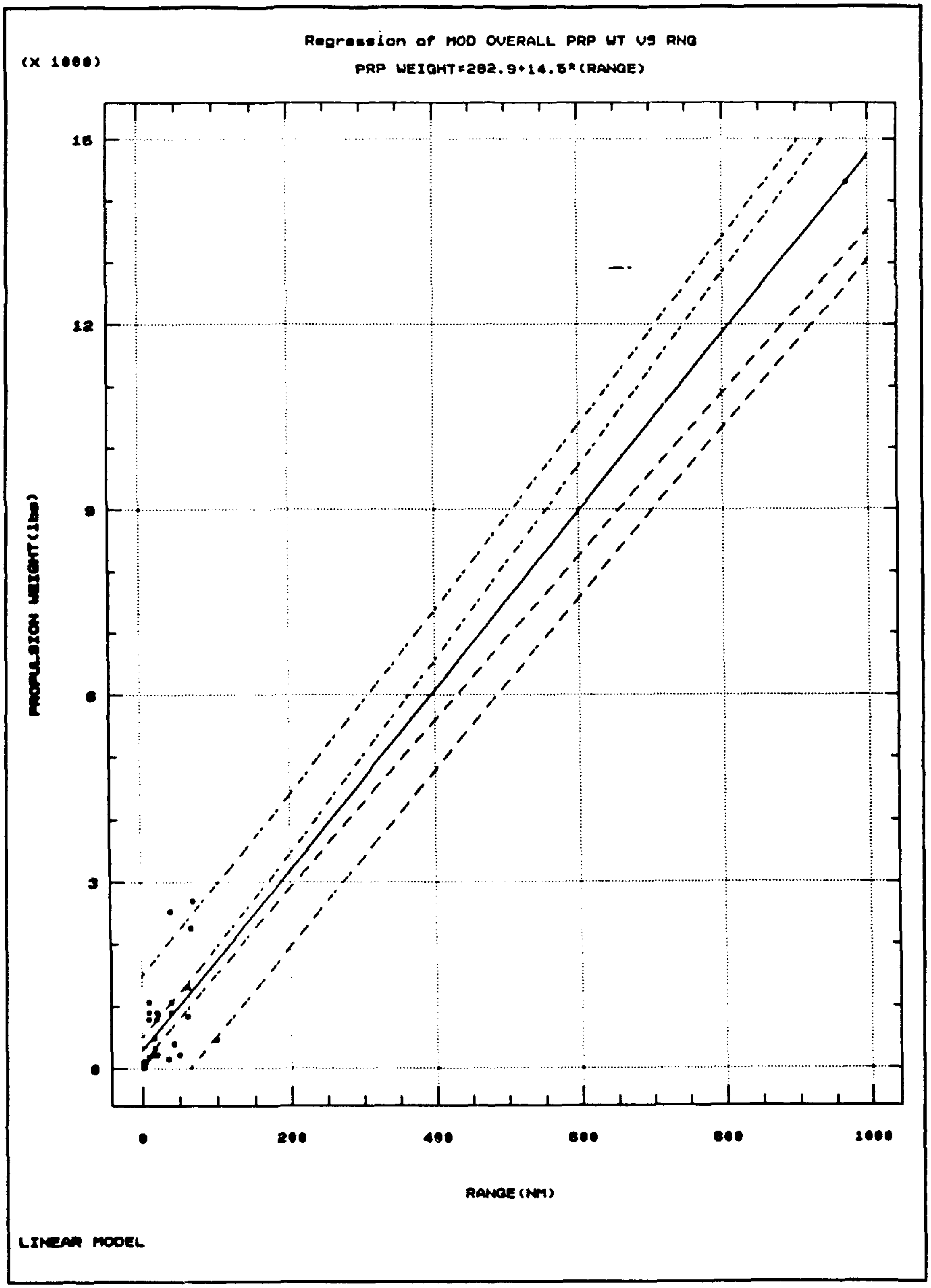

Figure B-43: Overall Rocket Prop Only Prop Wt vs Range

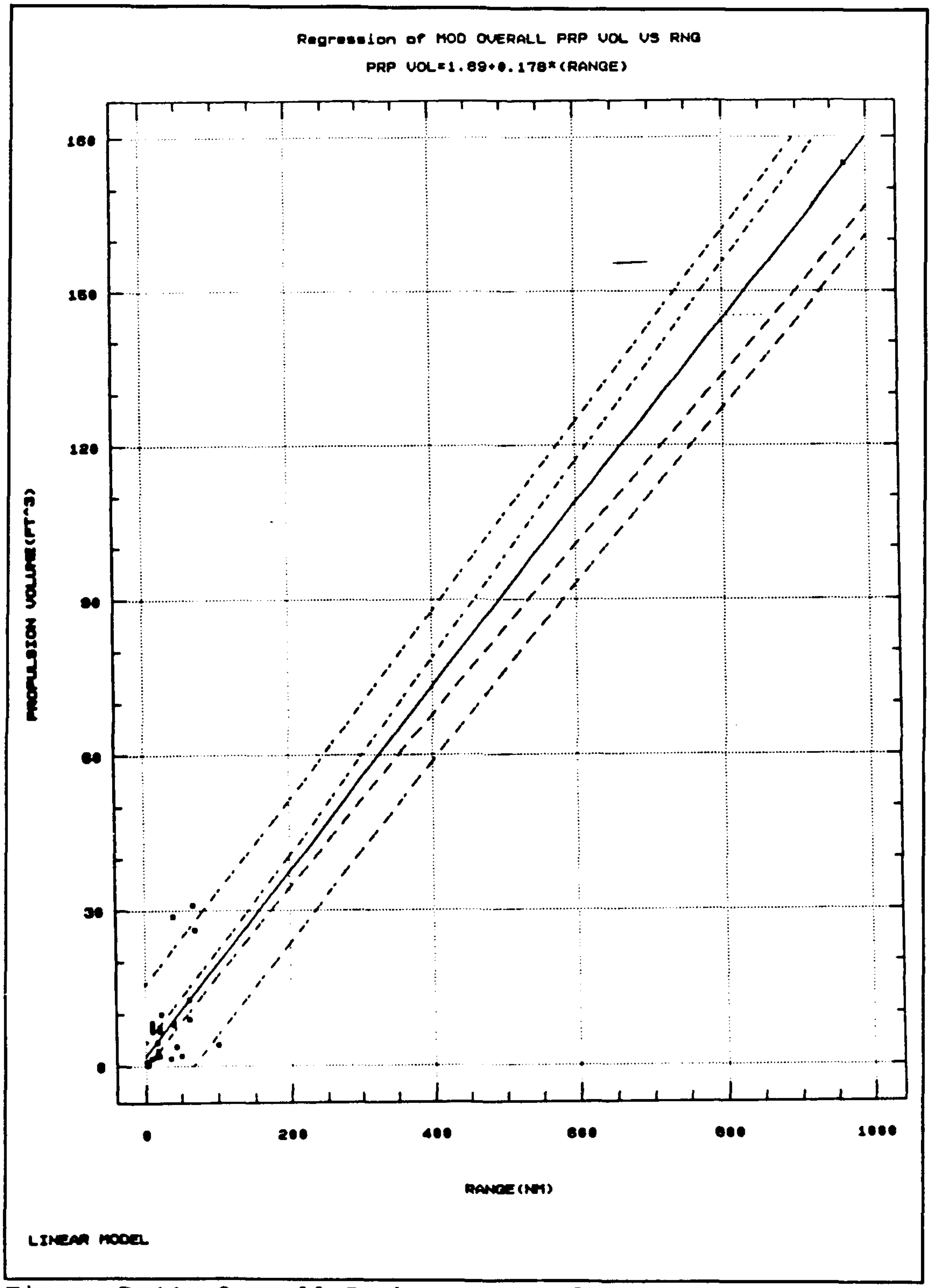

Figure B-44: Overall Rocket Prop Only Prop Vol vs Range

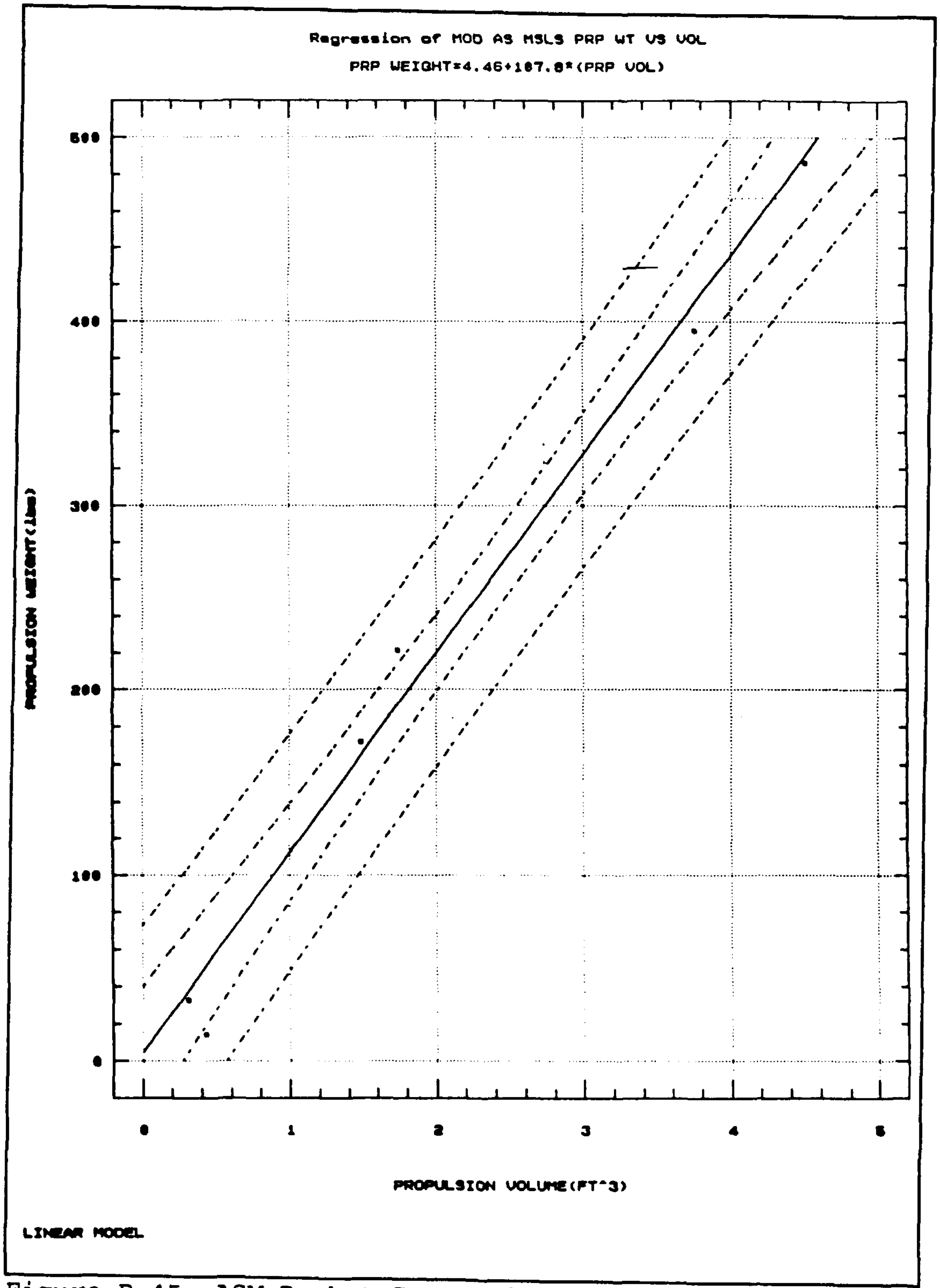

Figure B-45: ASM Rocket Prop Only Prop Wt vs Prop Vol

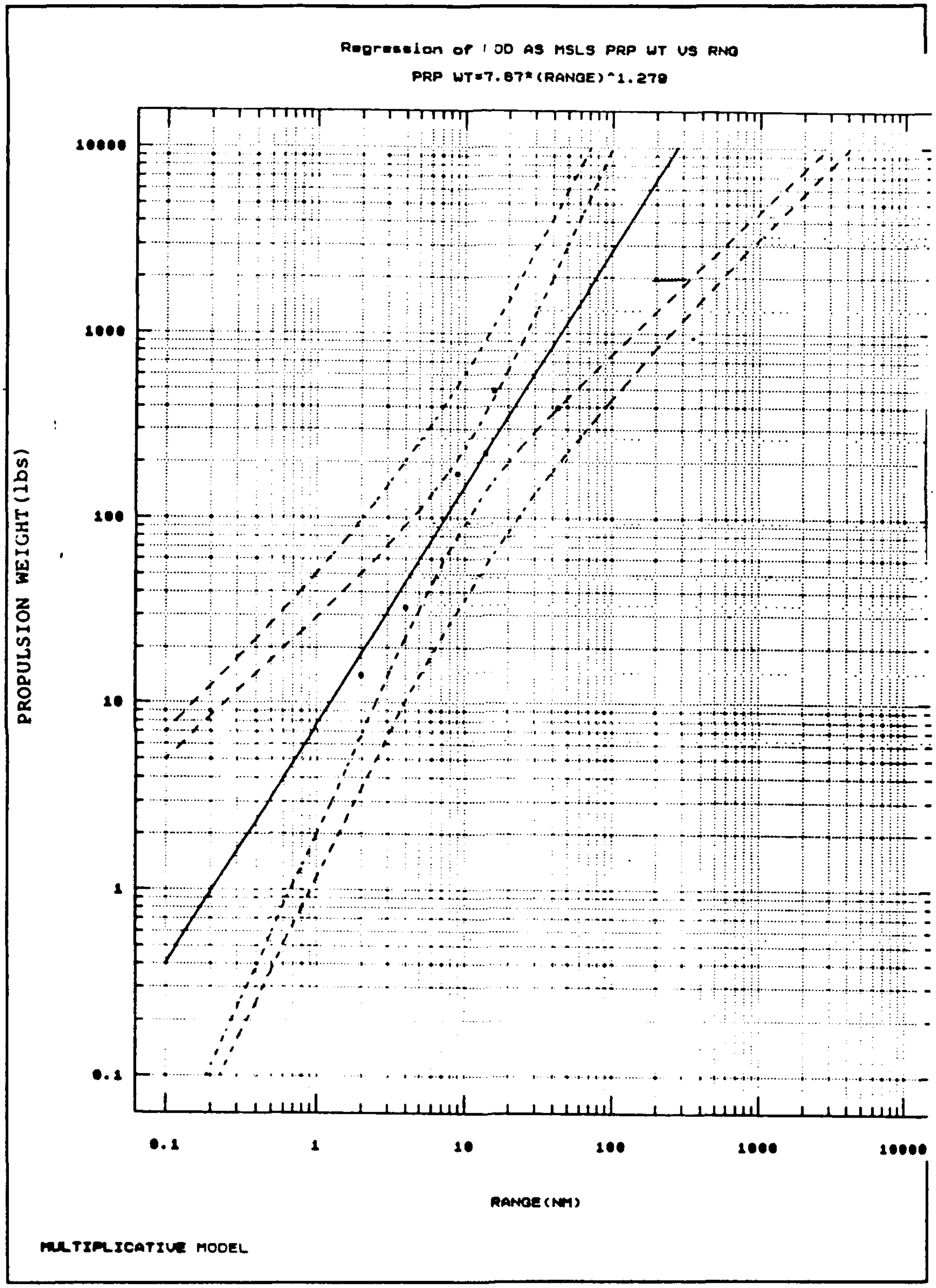

Figure B-46: ASM Rocket Prop Only Prop Wt vs Range

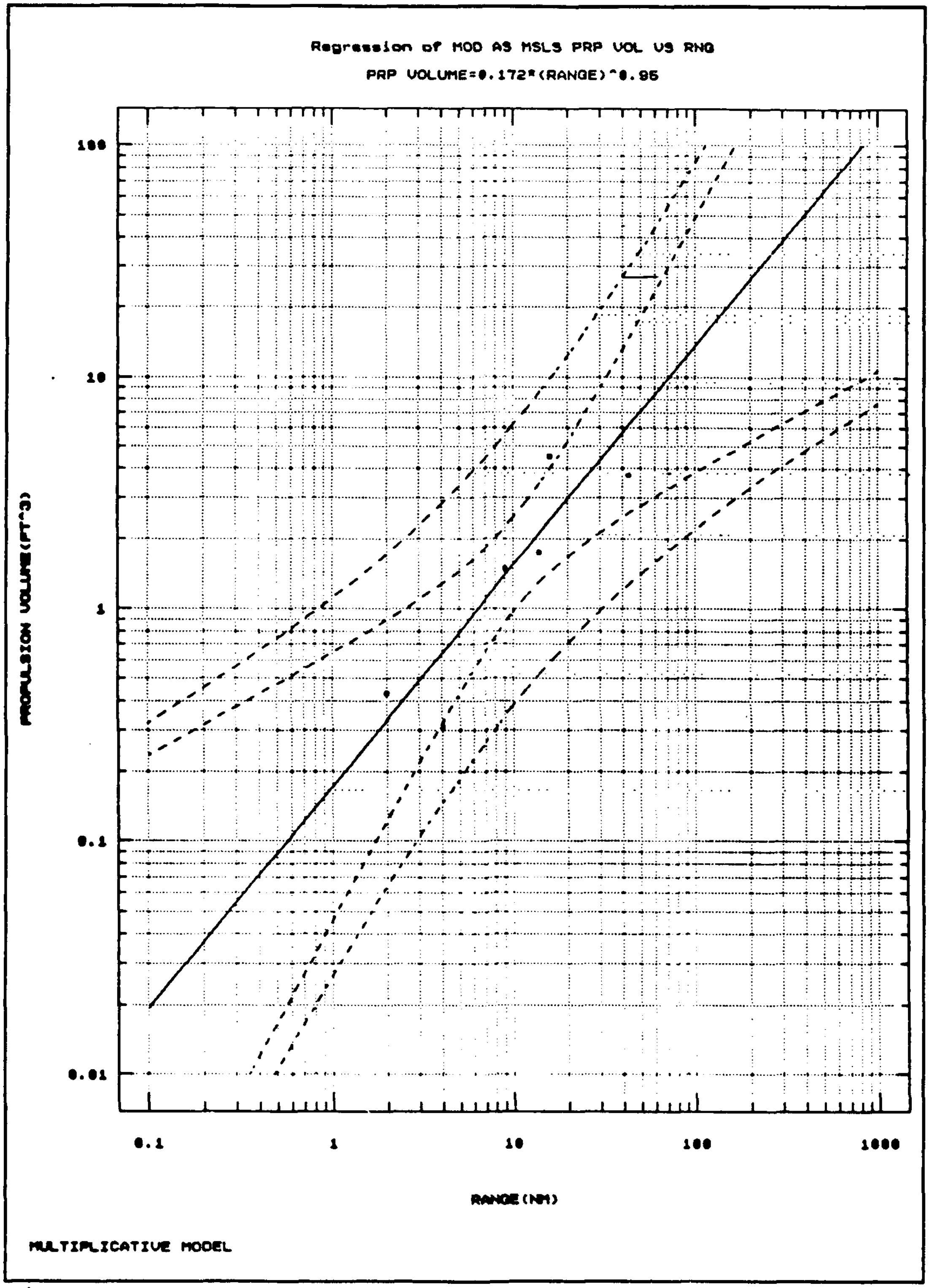

Figure B-47: ASM Rocket Prop Only Prop Vol vs Range

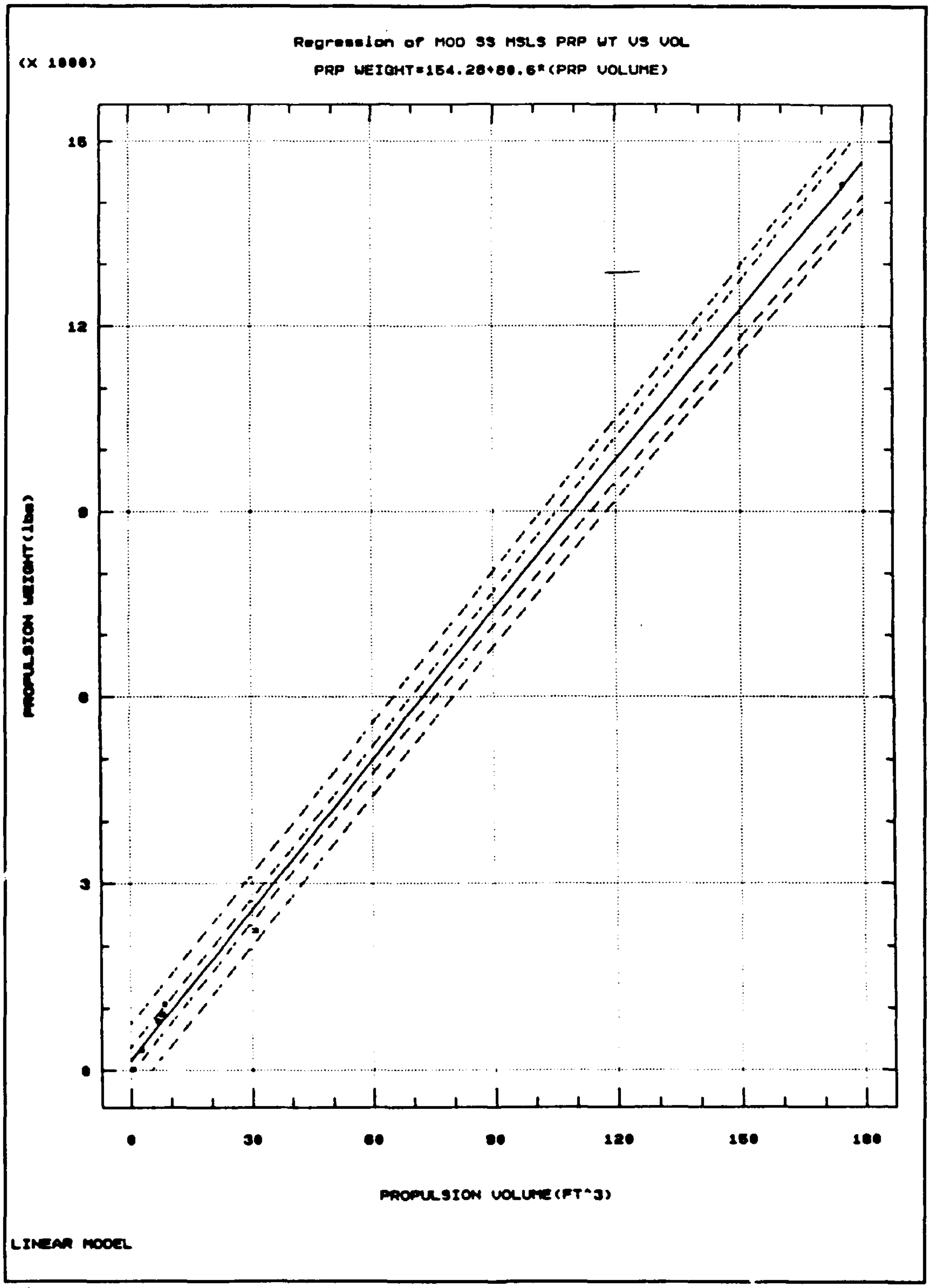

Figure B-48: SSM Rocket Prop Only Prop Wt vs Prop Vol

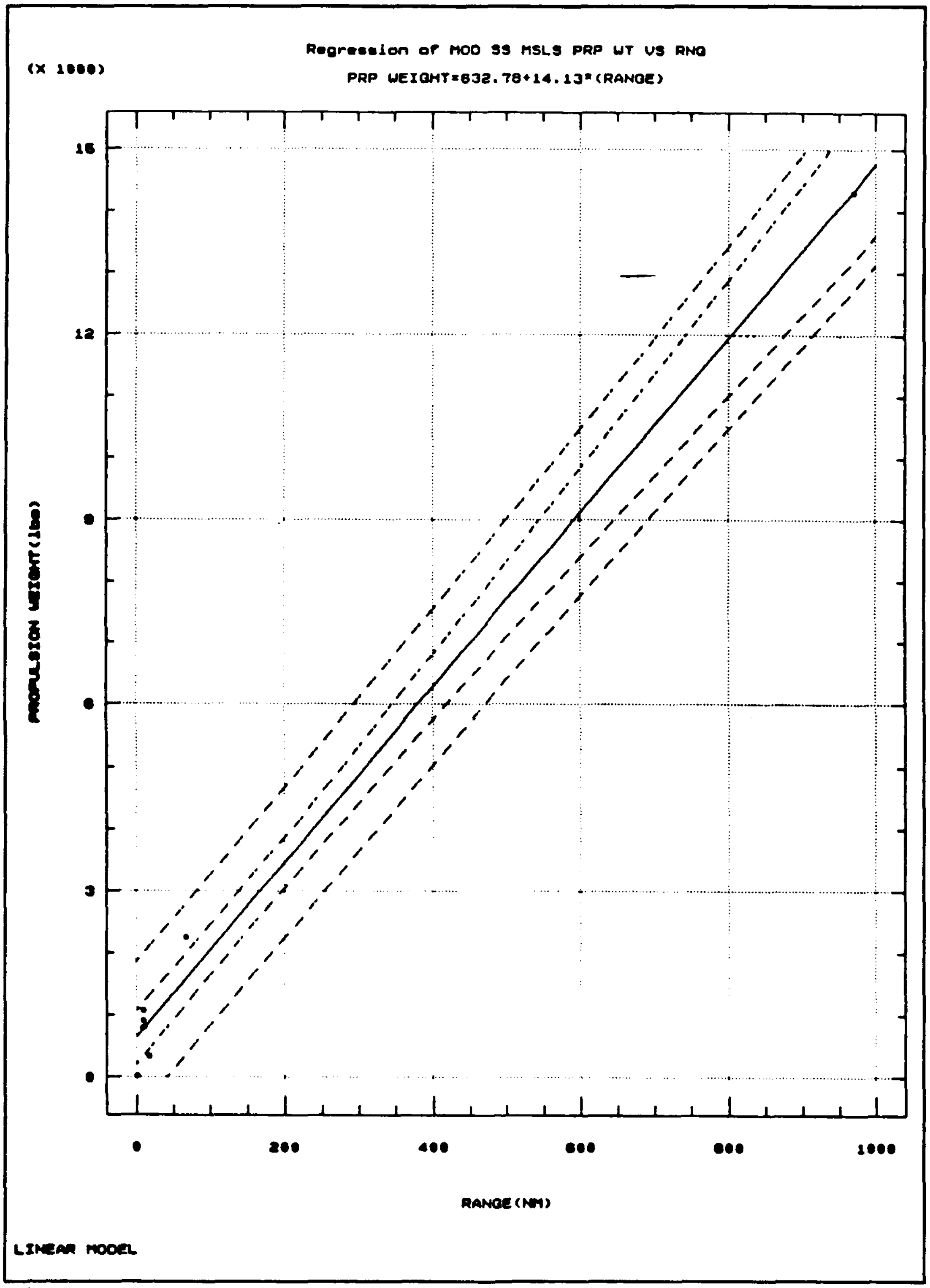

Figure B-49: SSM Rocket Prop Only Prop Wt vs Range

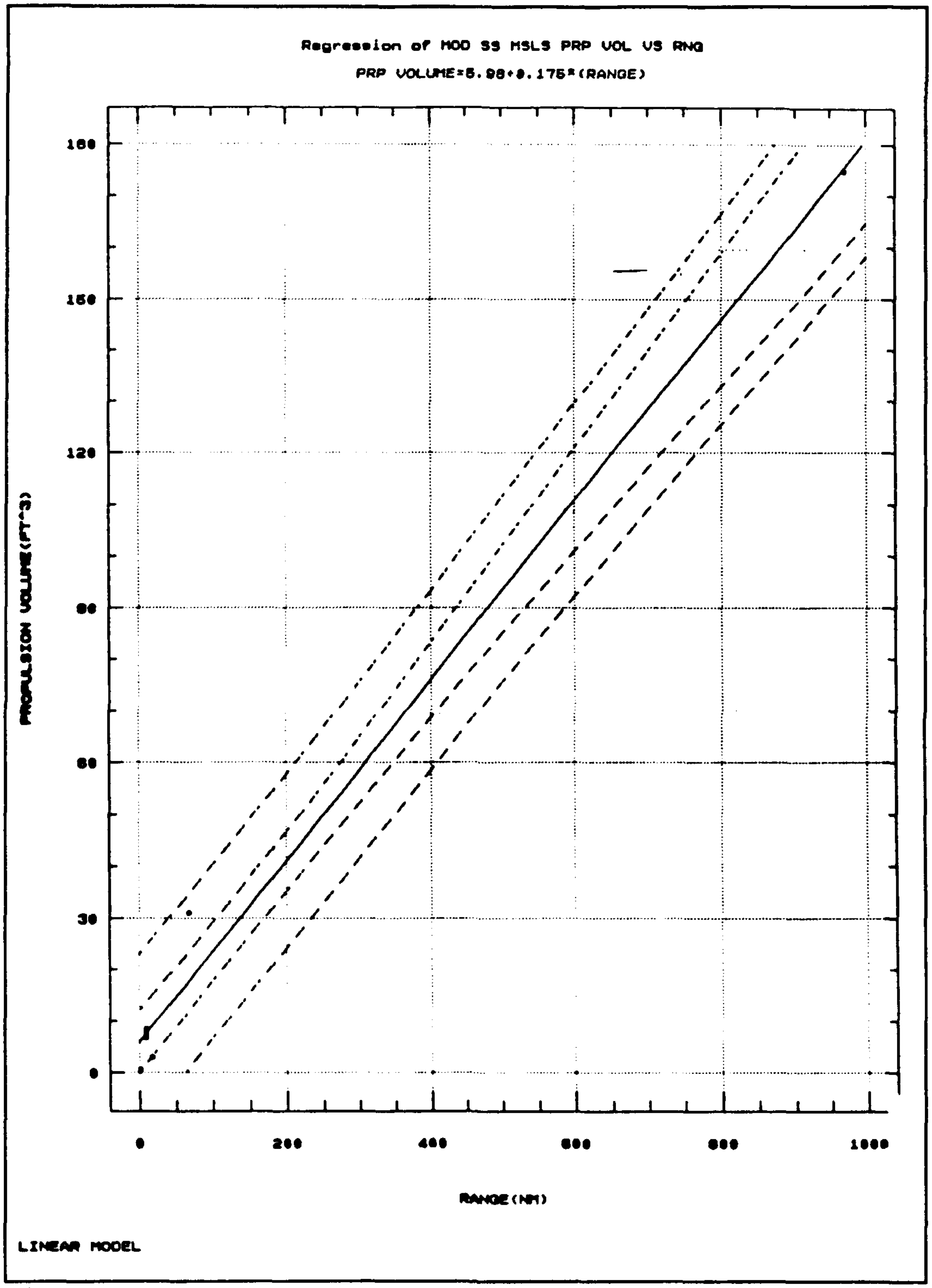

Figure B-50: SSM Rocket Prop Only Prop Vol vs Range

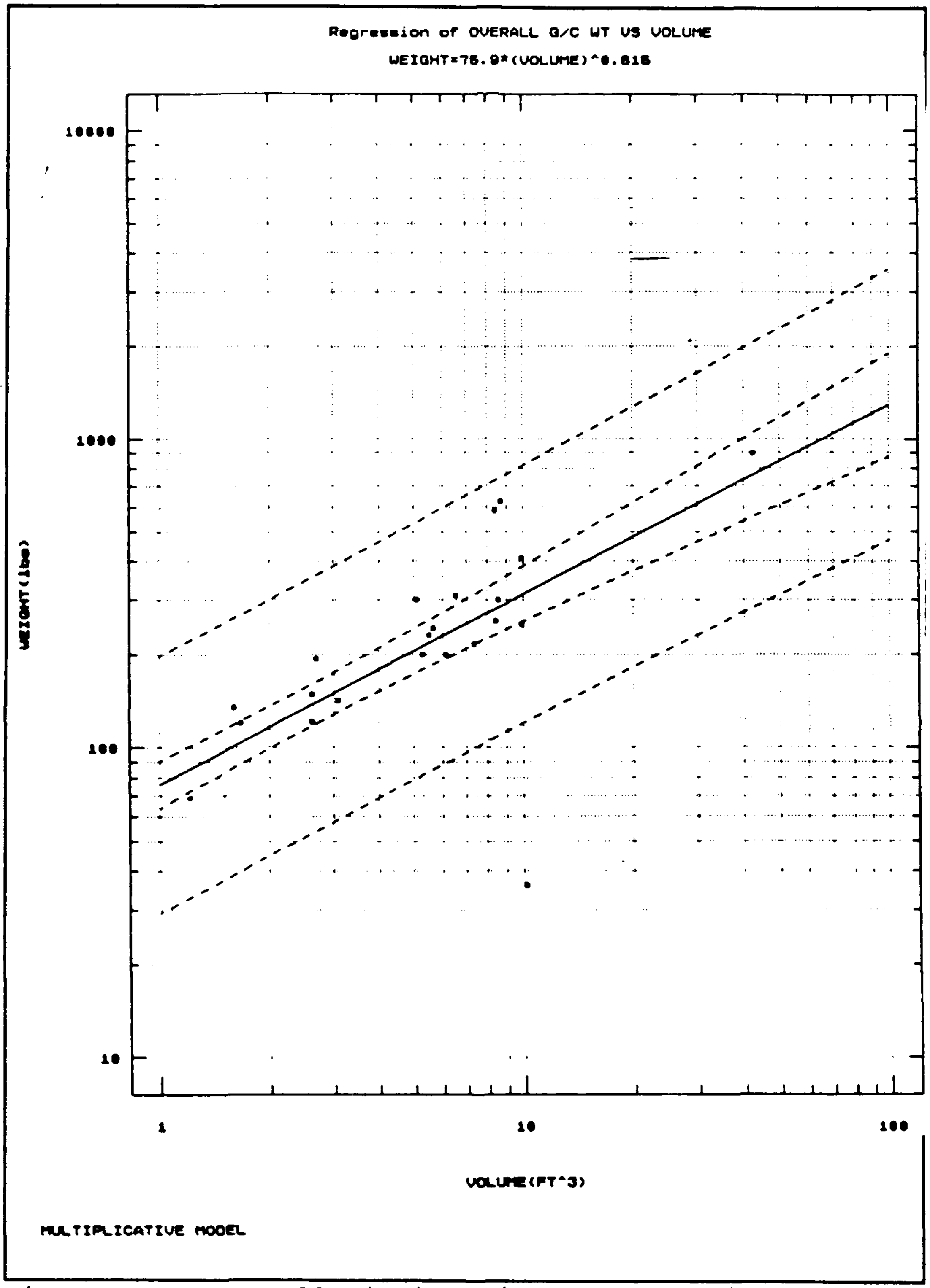

Figure B-51: Overall Missile G/C Weight vs G/C Volume

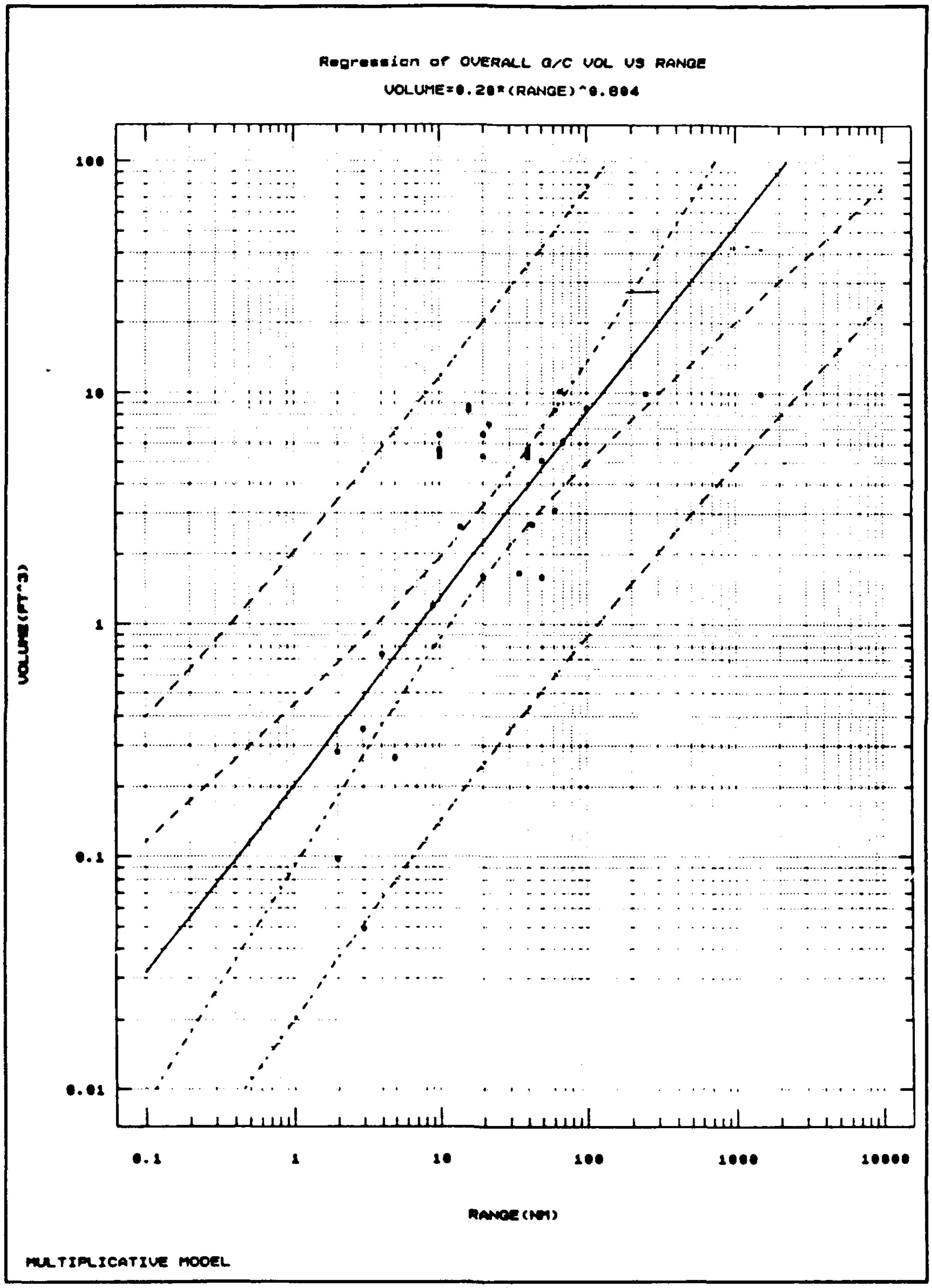

Figure B-52: Overall Missile G/C Volume vs Range

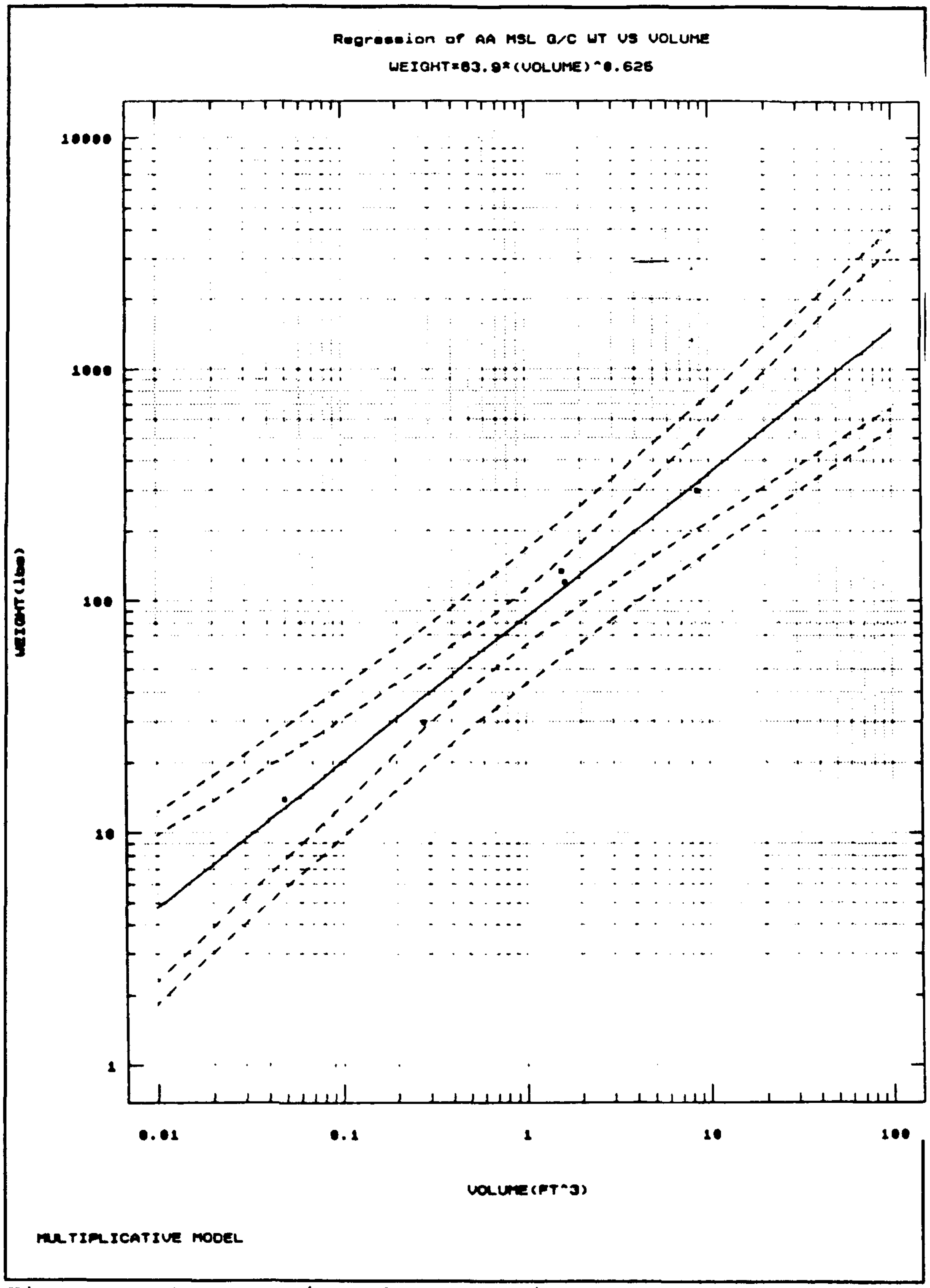

Figure B-53: AAM G/C Weight vs G/C Volume

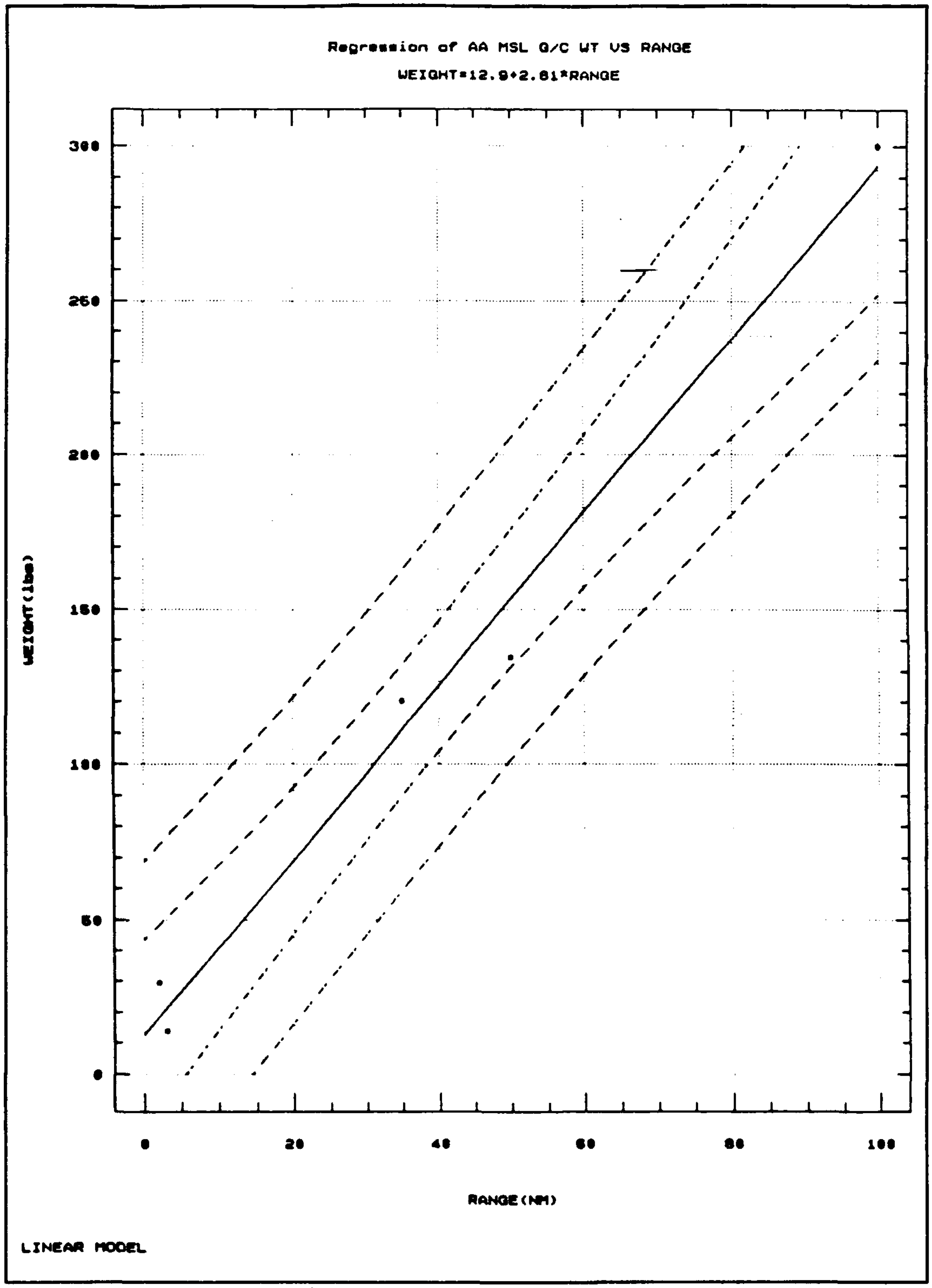

Figure B-54: AAM G/C Weight vs Range

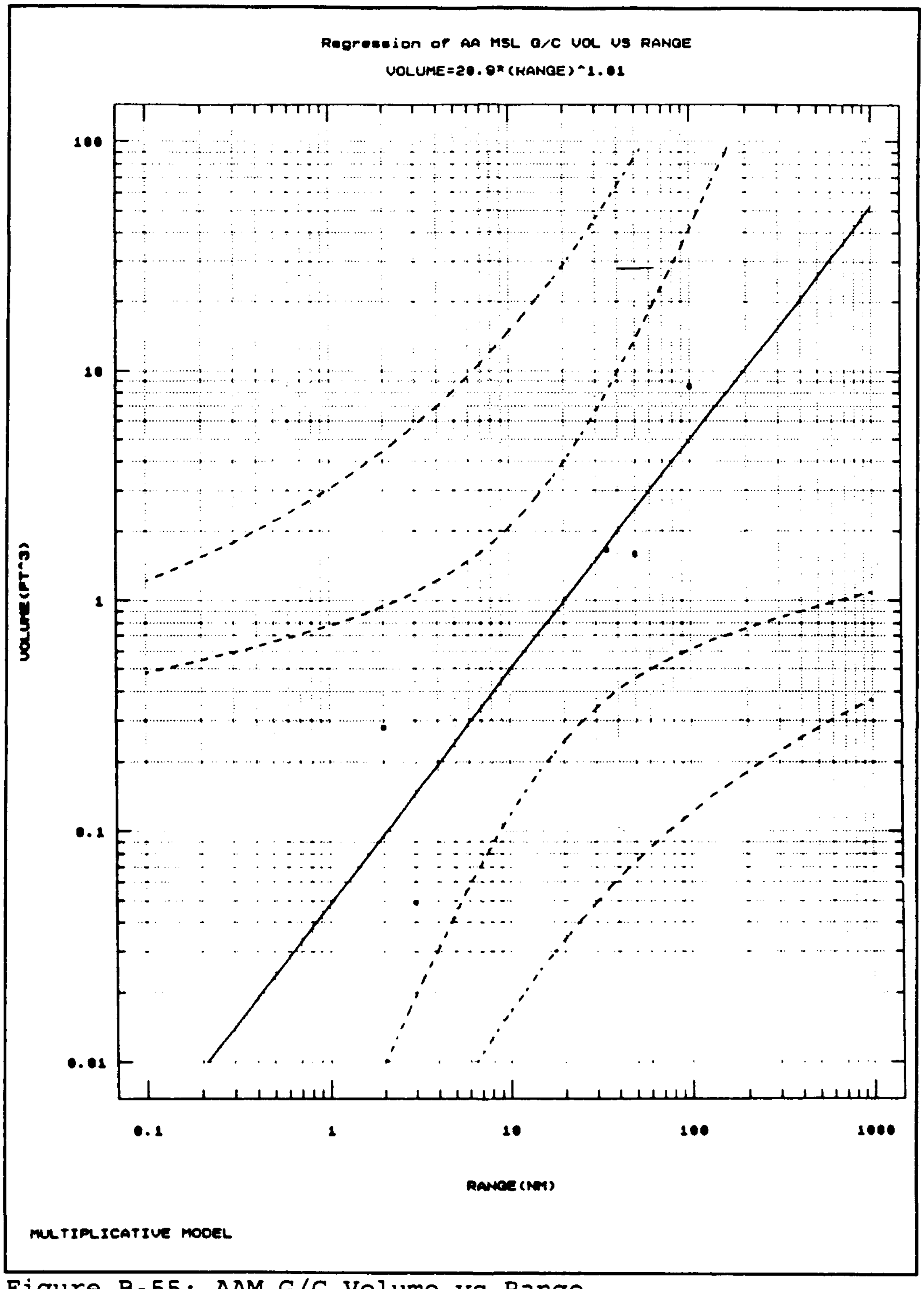

Figure B-55: AAM G/C Volume vs Range

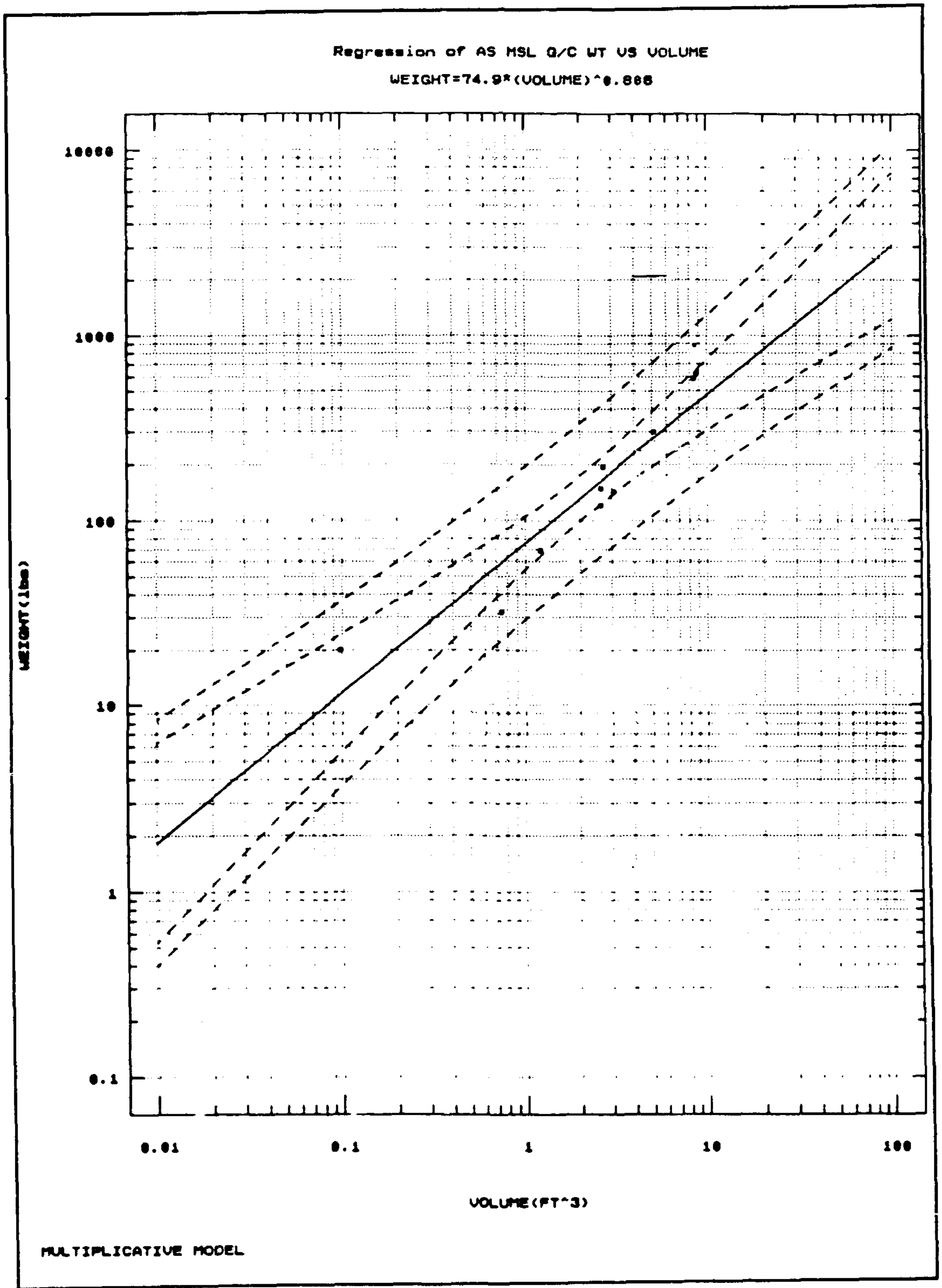

Figure B-56: ASM G/C Weight vs G/C Volume

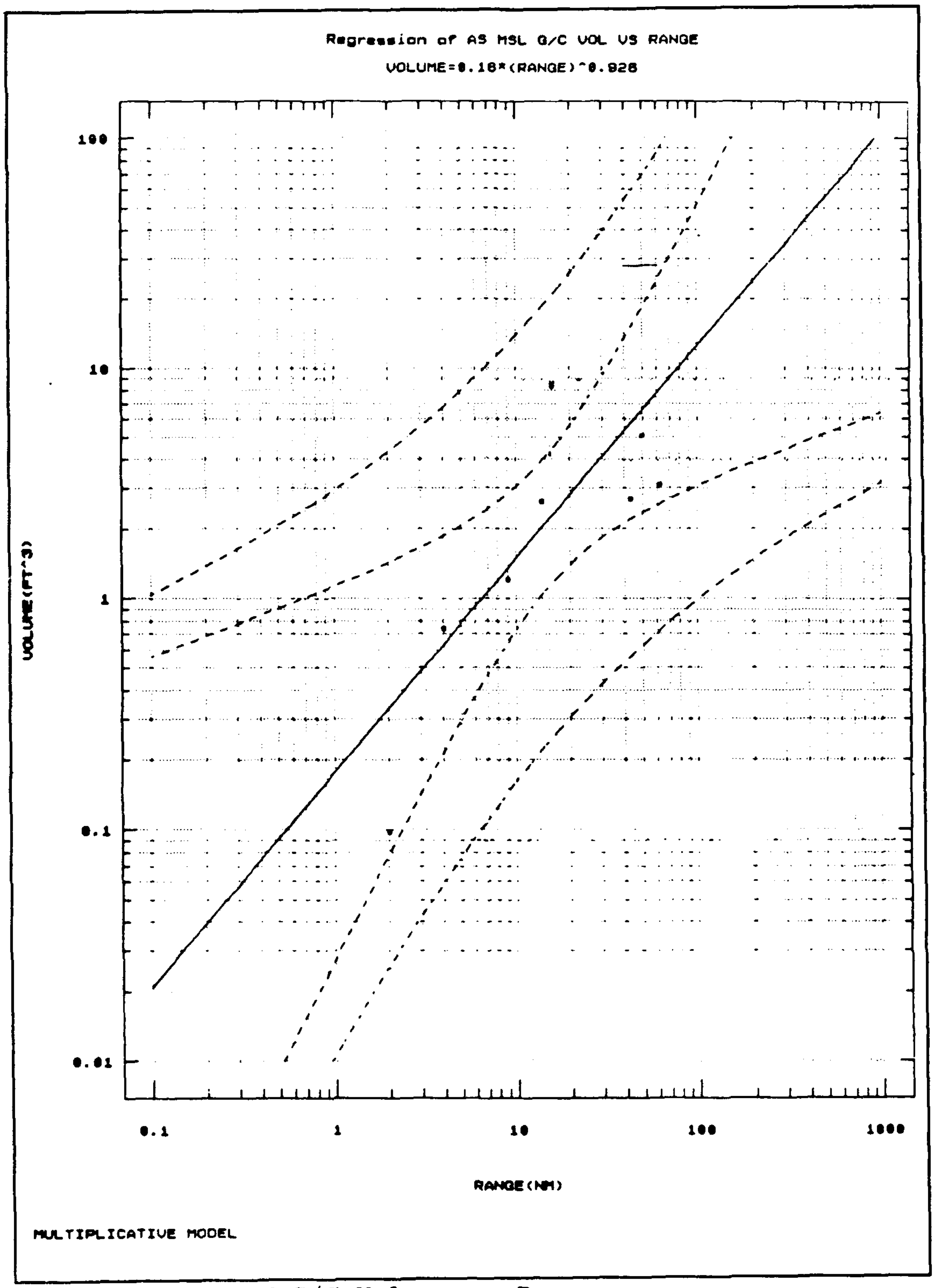

Figure B-57: ASM G/C Volume vs Range

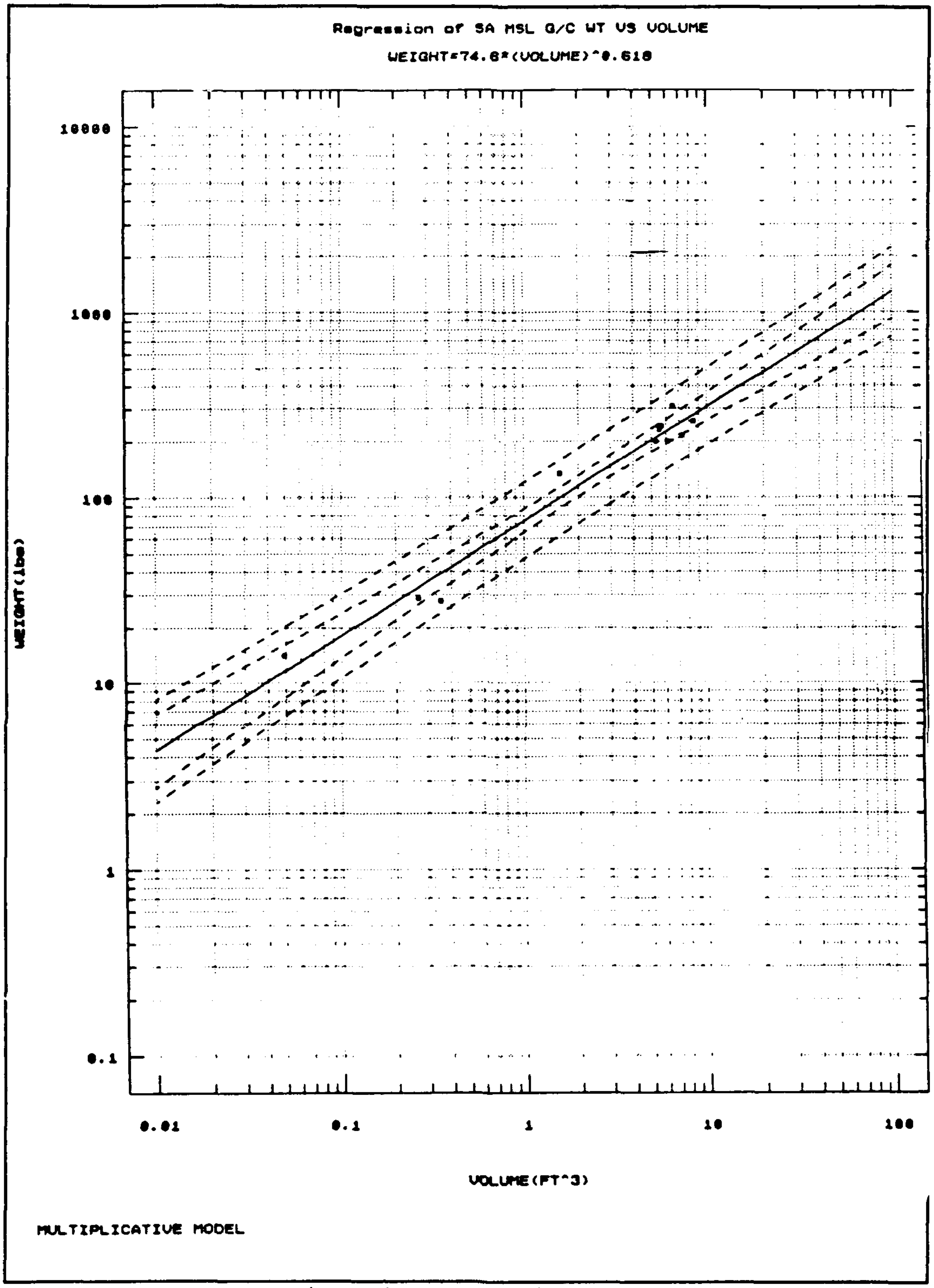

Figure B-58: SAM G/C Weight vs G/C Volume

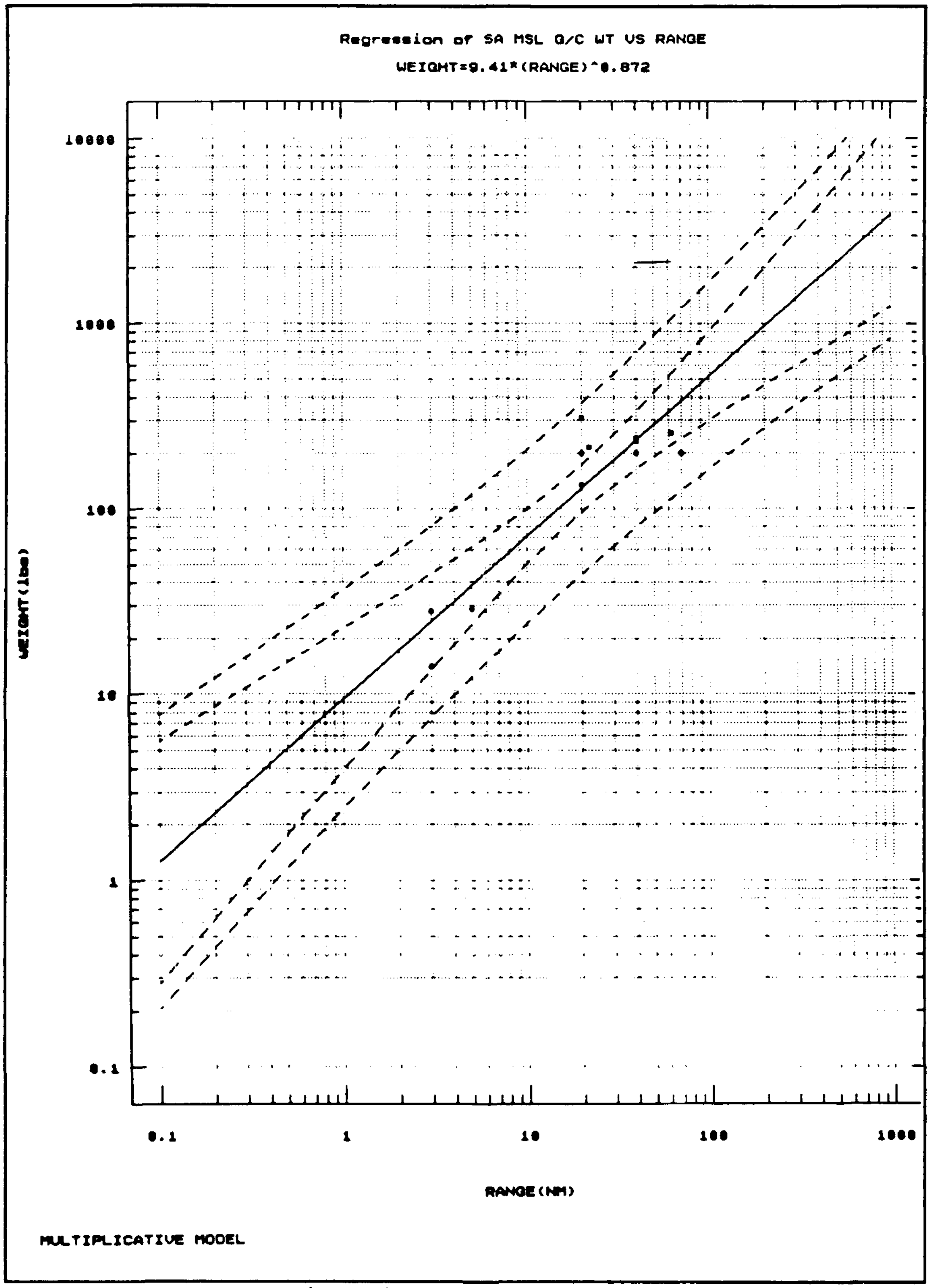

Figure B-59: SAM G/C Weight vs Range

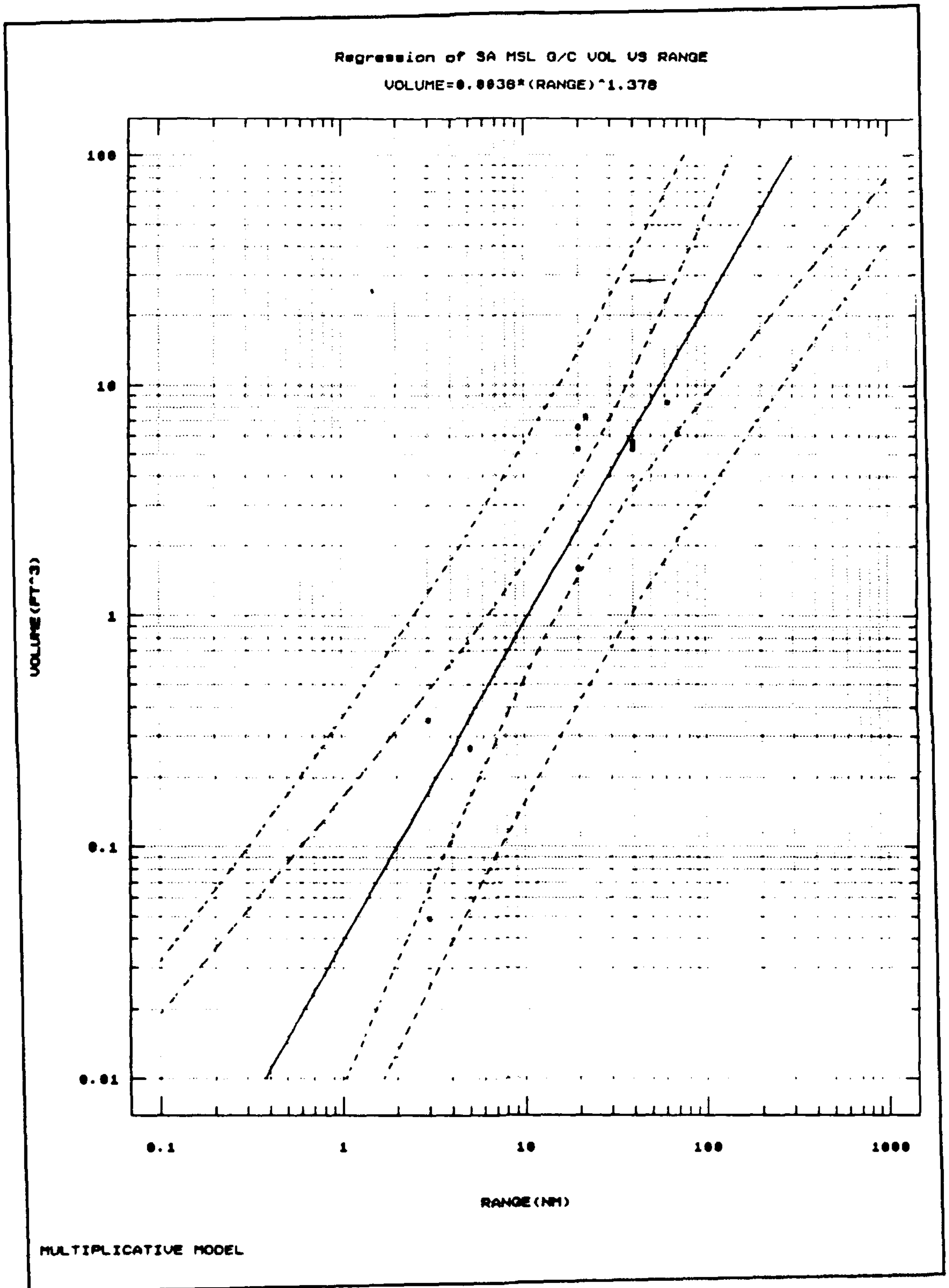

Figure B-60: G/C Volume vs Range

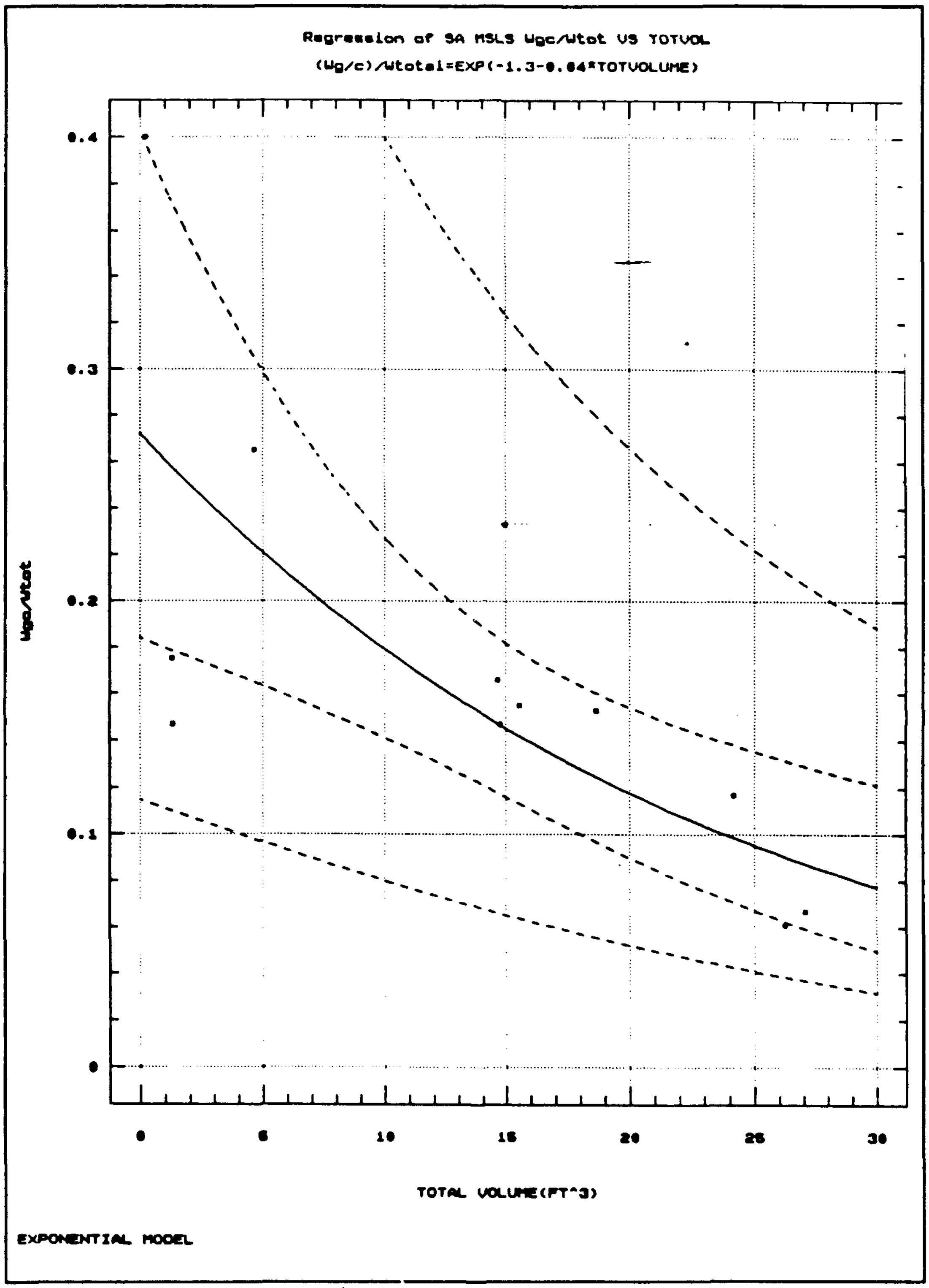

Figure B-61: SAM Wgc/Wt vs Volume

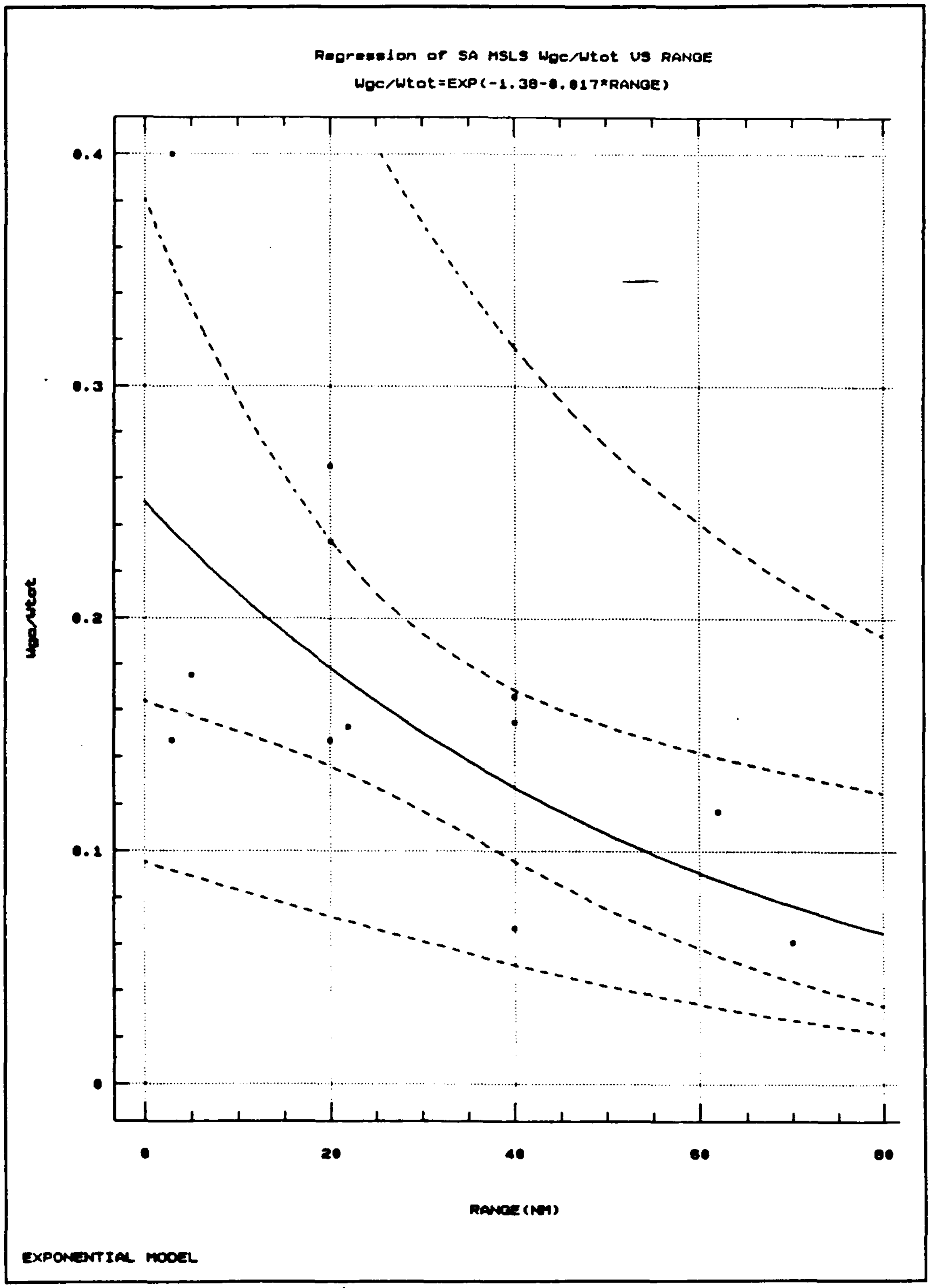

Figure B-62: SAM Wgc/Wt vs Range

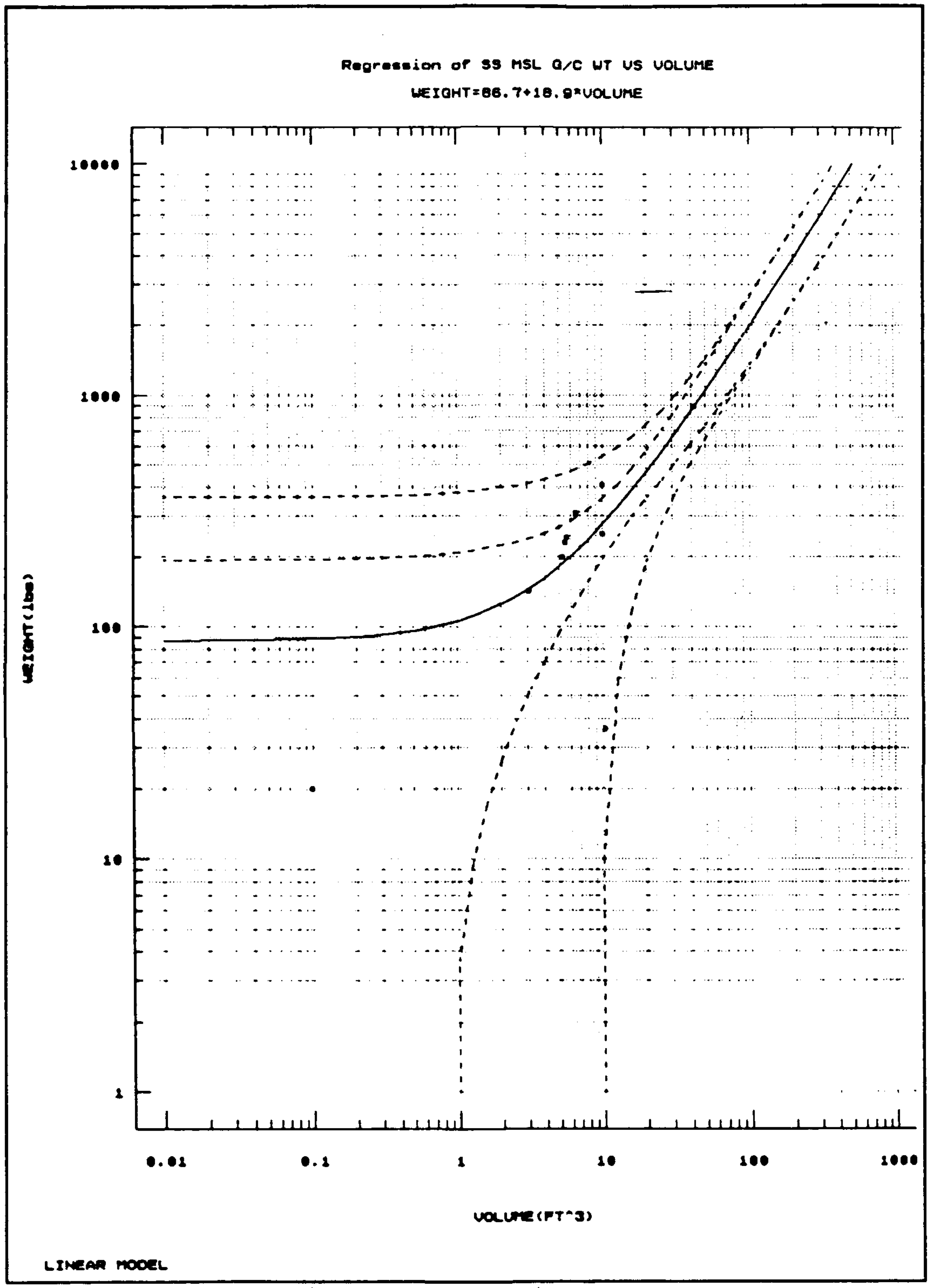

Figure B-63: SSM G/C Weight vs G/C Volume

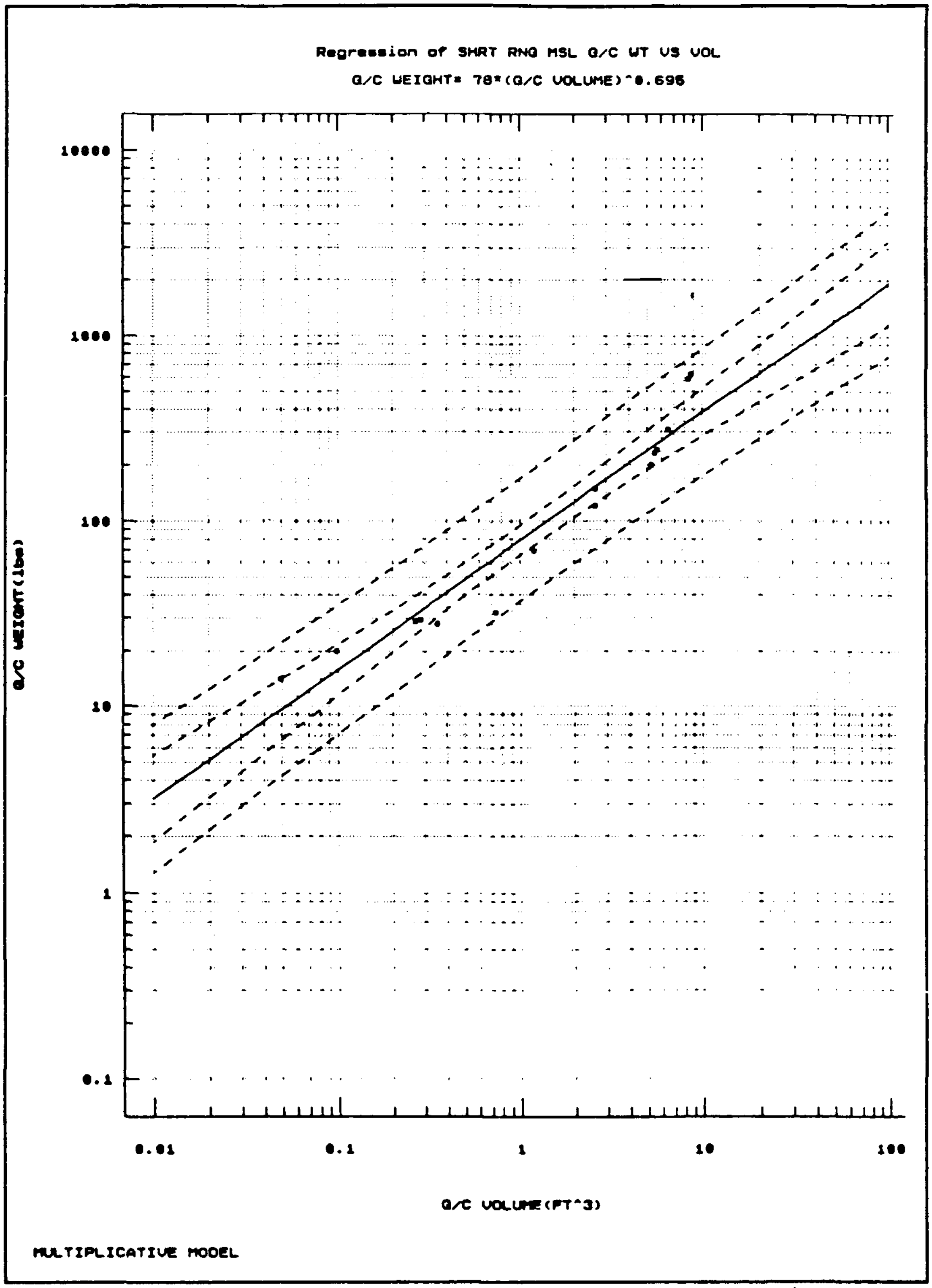

Figure B-64: Short Range Missile G/C Weight vs G/C Volume

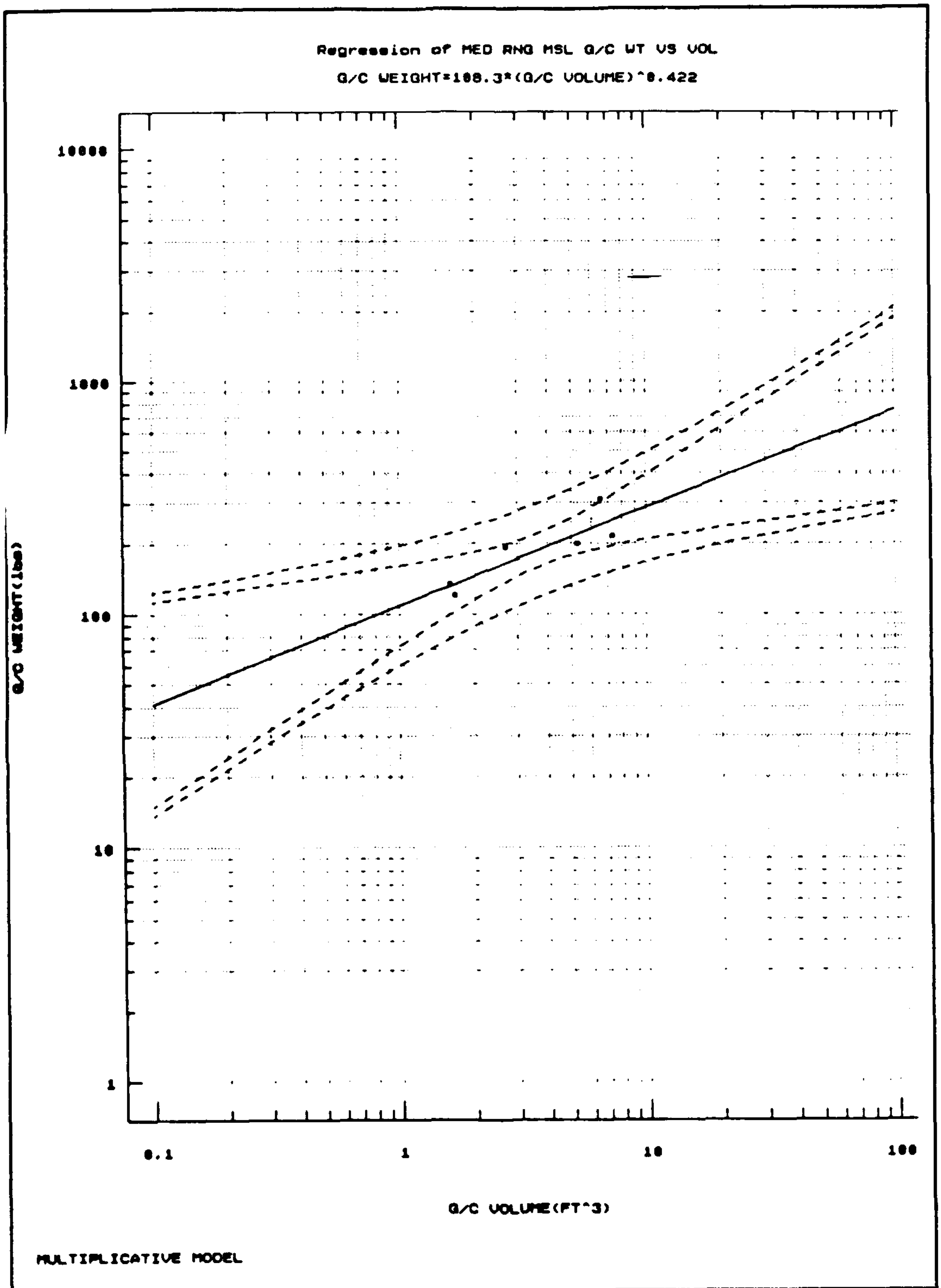

Figure B-65: Medium Range Missile G/C Weight vs G/C Volume

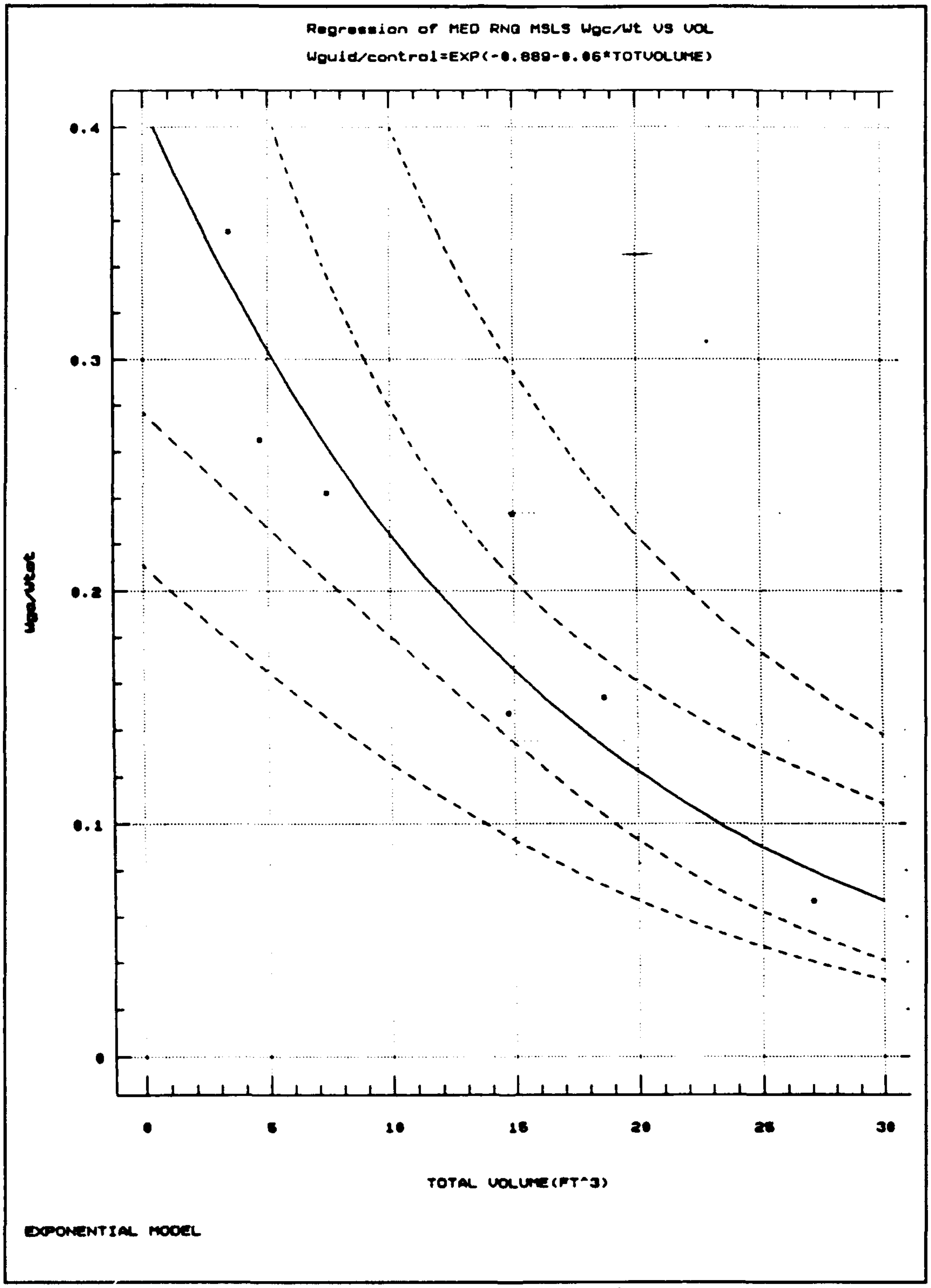

Figure B-66: Medium Range Missile Wgc/Wt vs Volume

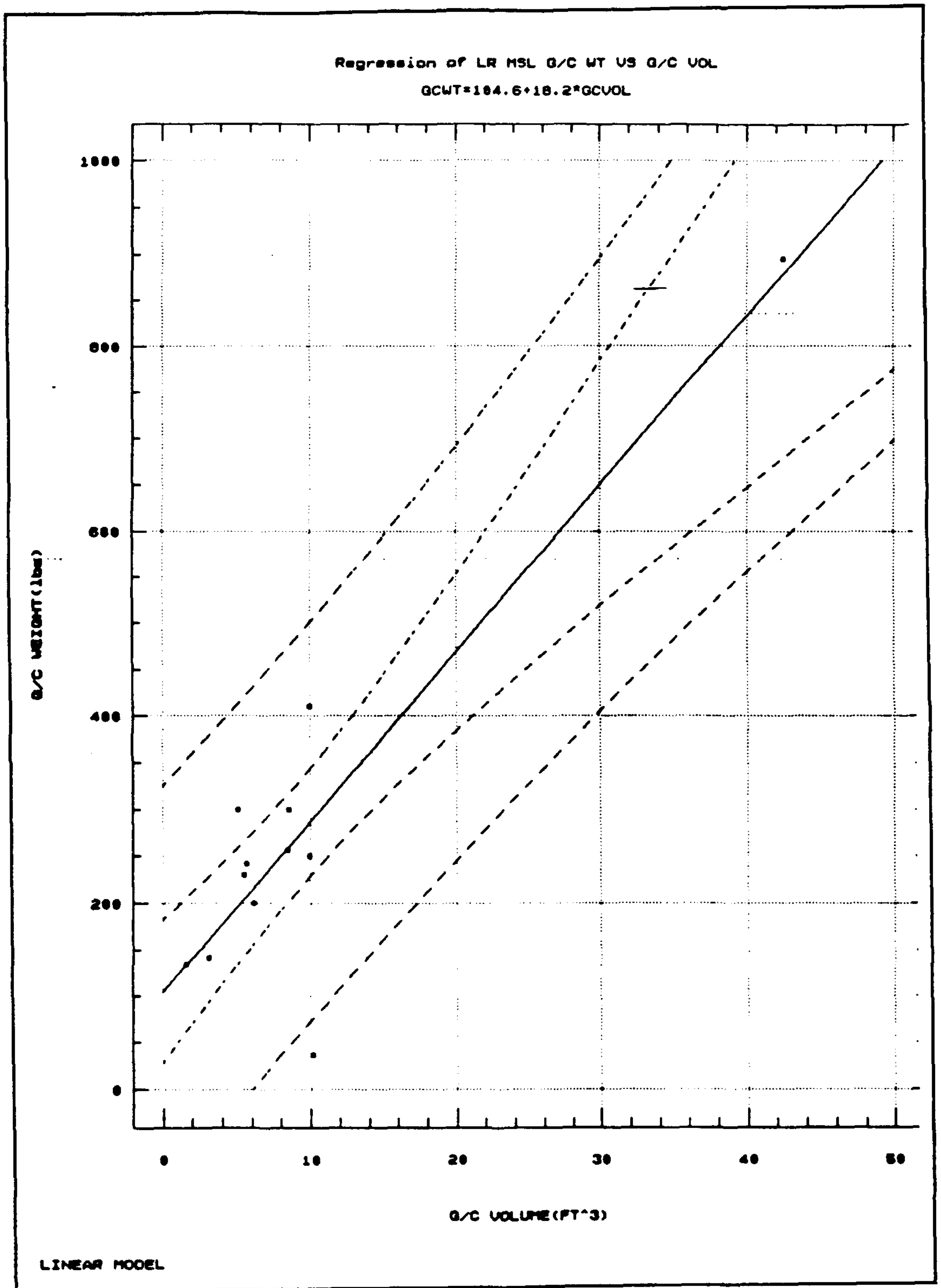

Figure B-67: Long Range Missile G/C Weight vs G/C Volume

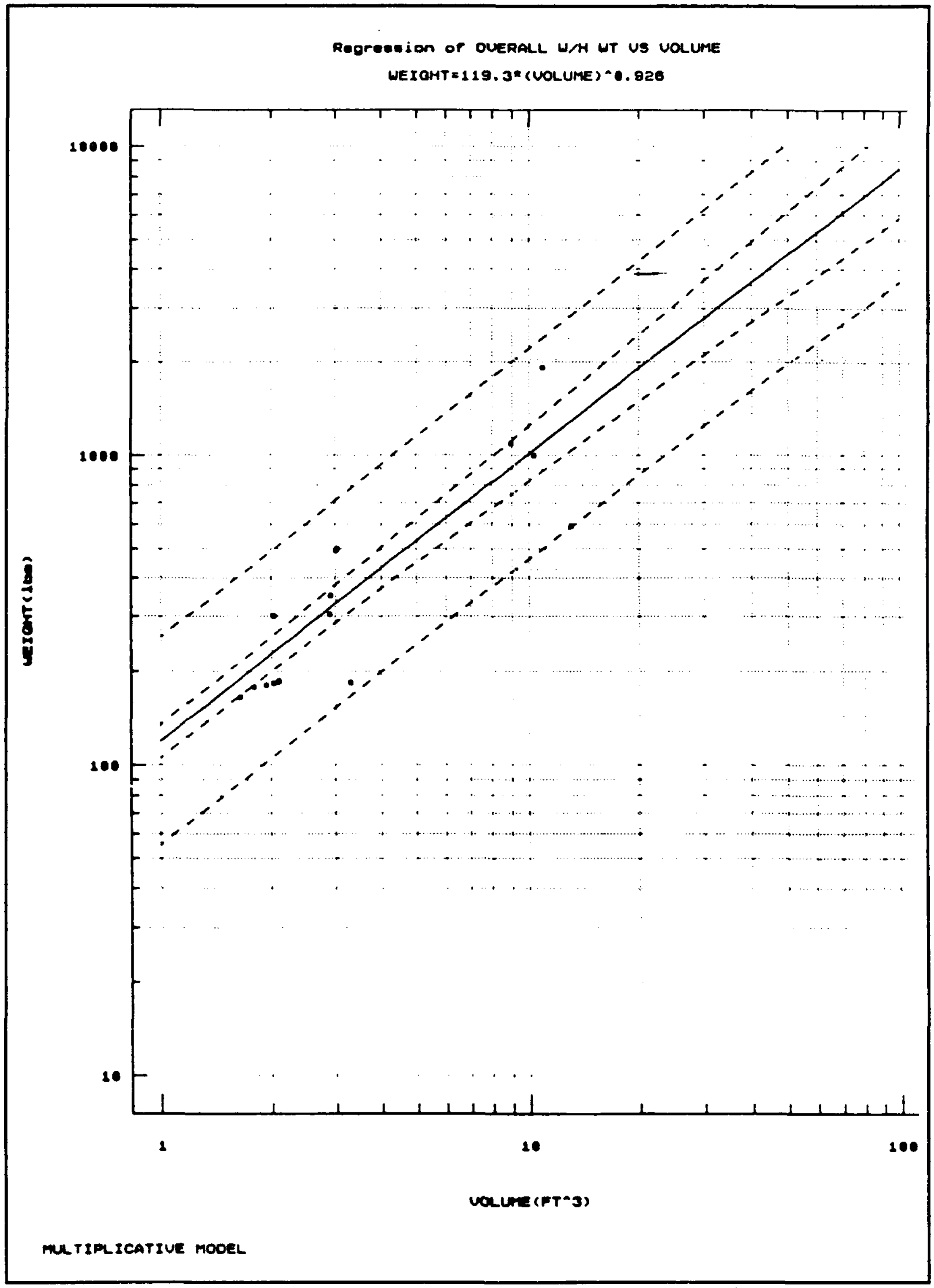

Figure B-68: Overall Missile W/H Weight vs W/H Volume

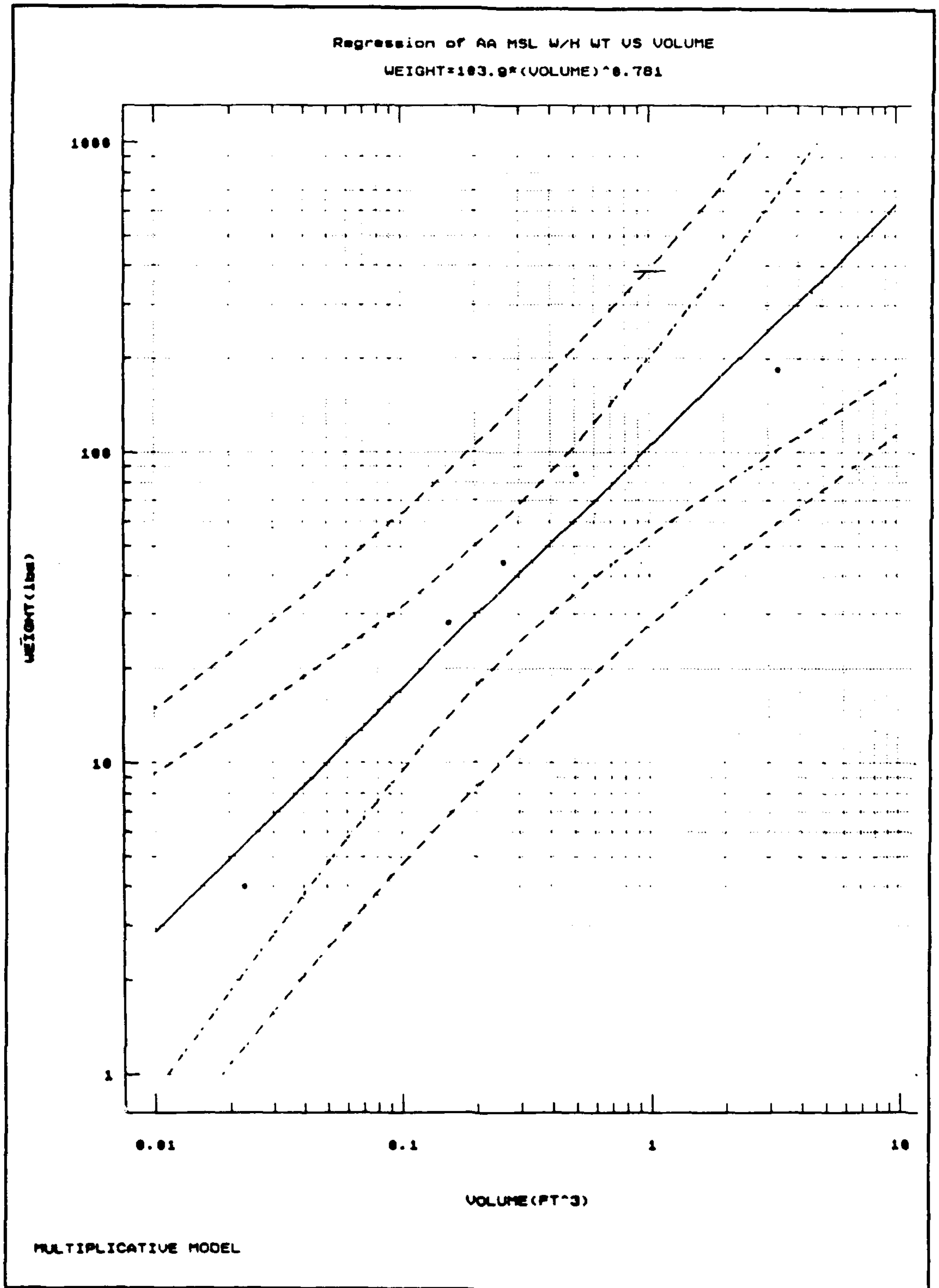

Figure B-69: AAM W/H Weight vs W/H Volume

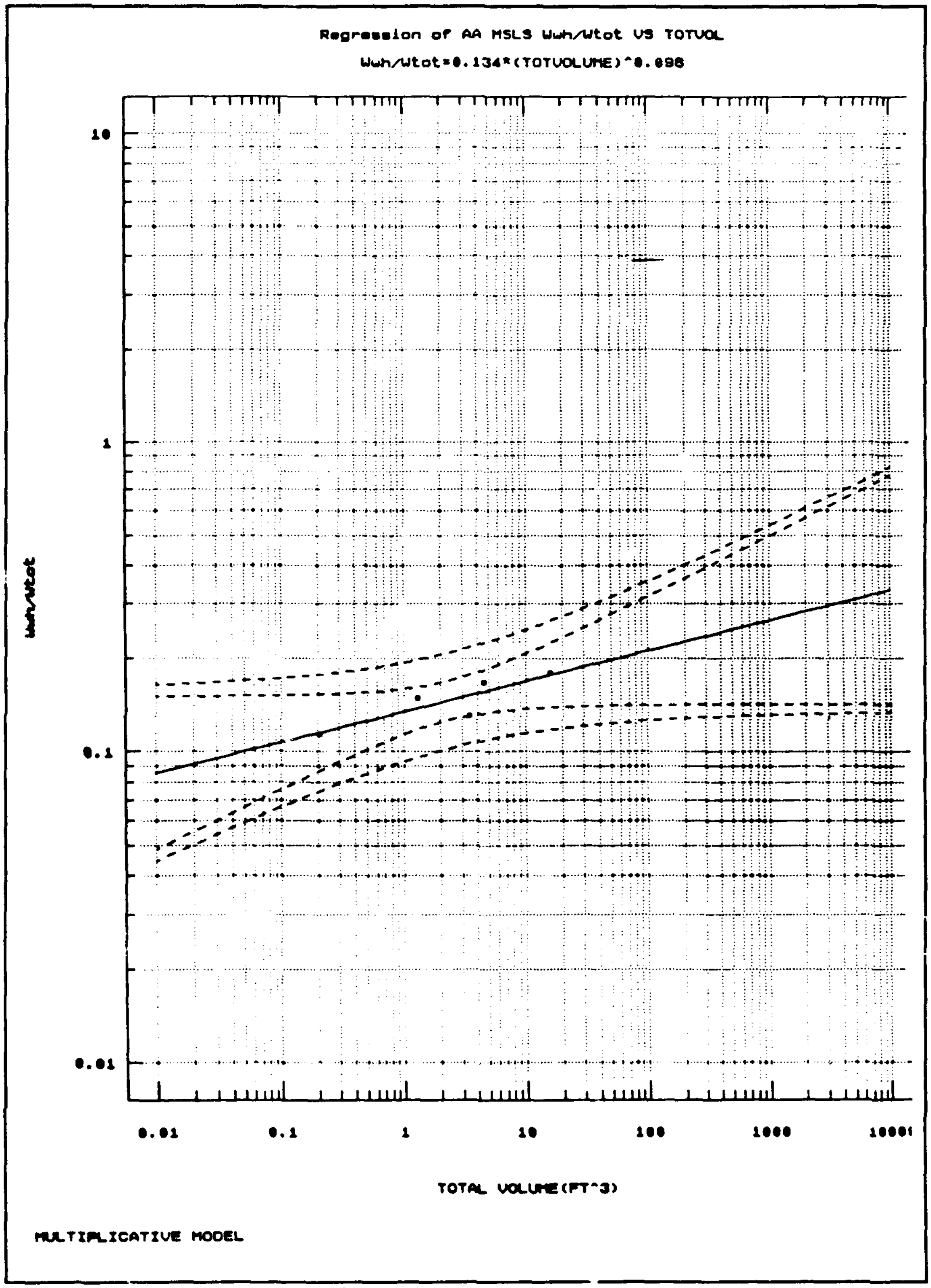

Figure B-70: AAM Wwh/Wt vs Volume

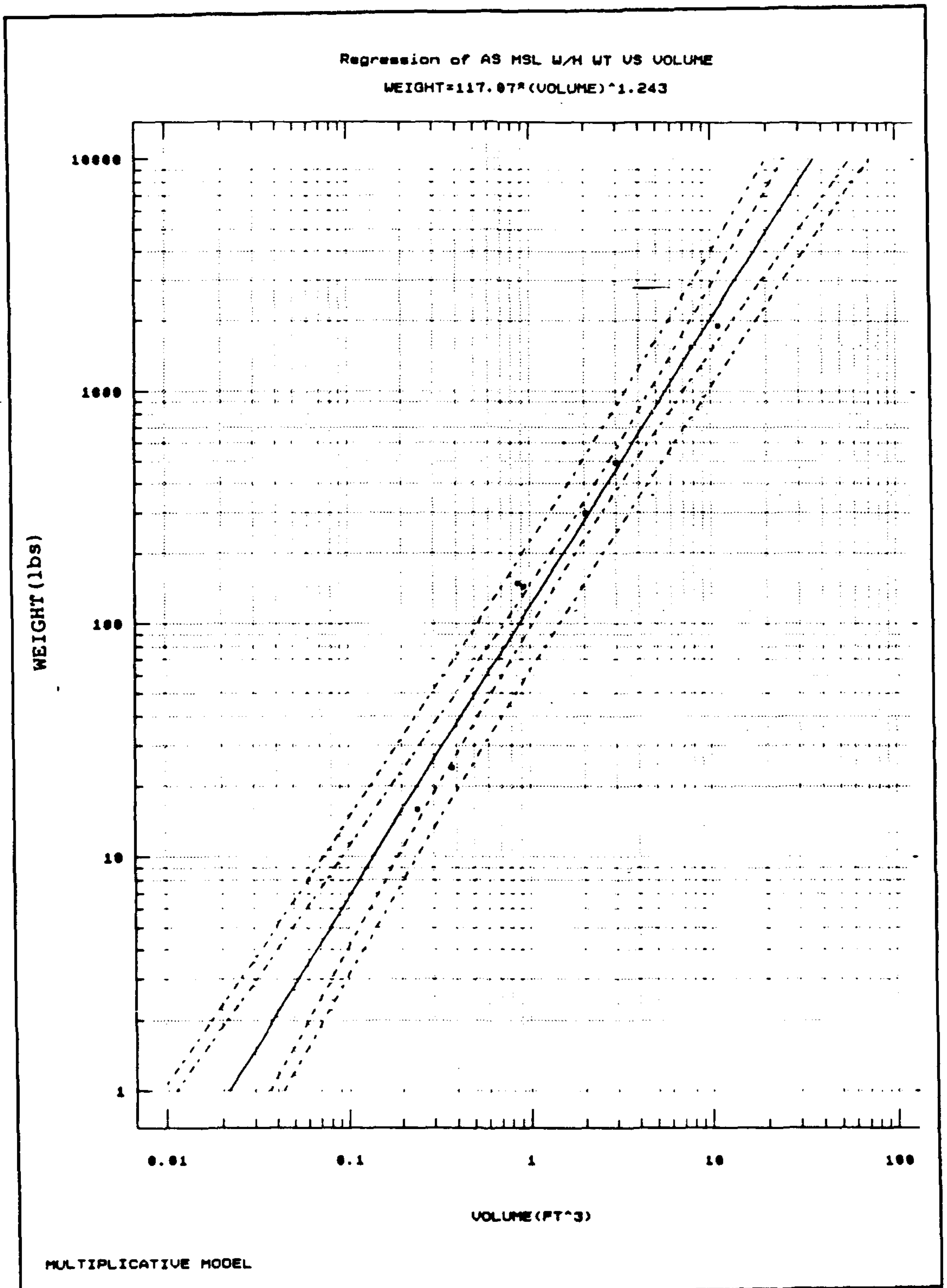

Figure B-71: ASM W/H Weight vs W/H Volume

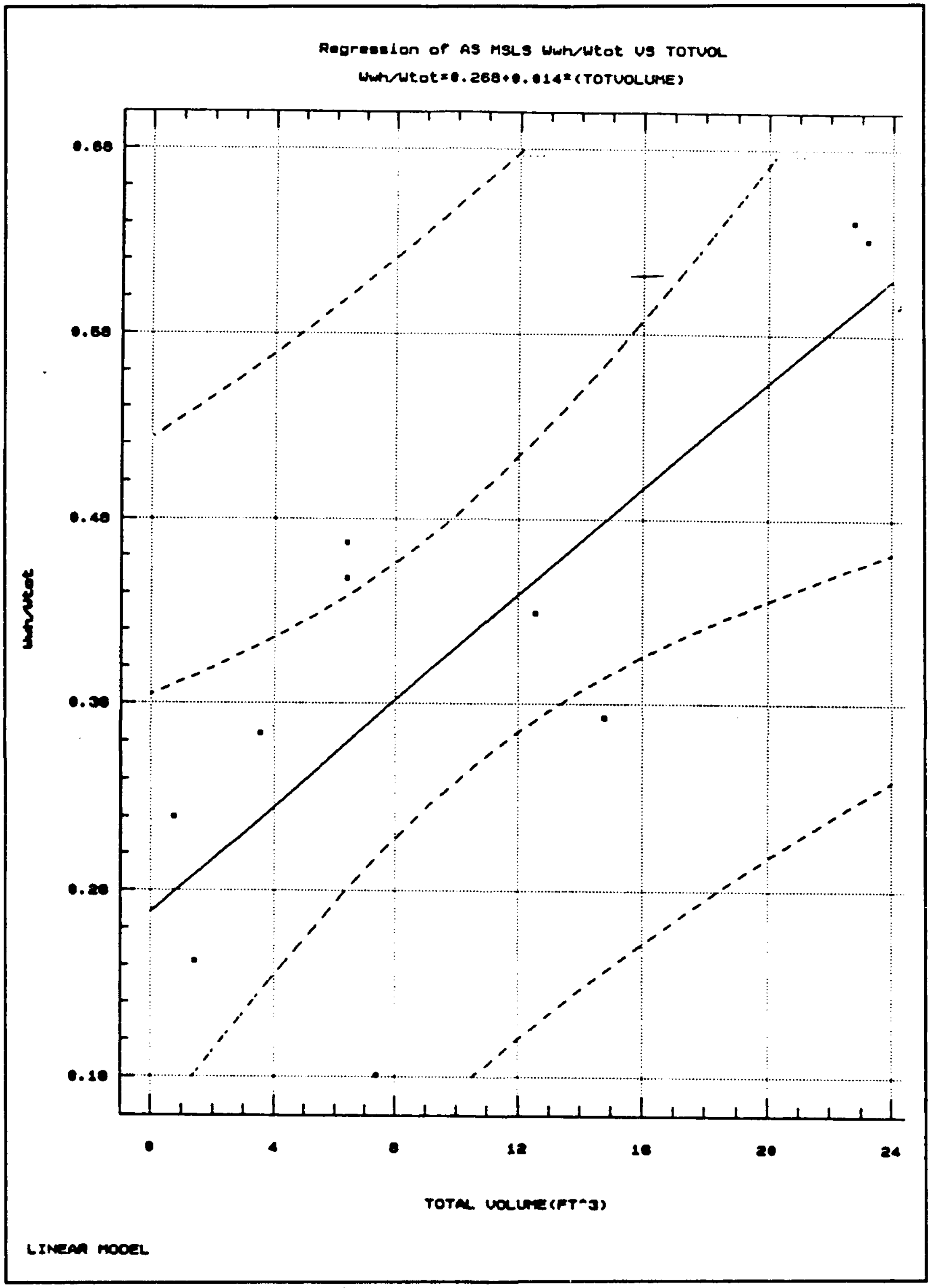

Figure B-72: ASM Wwh/Wt vs Volume

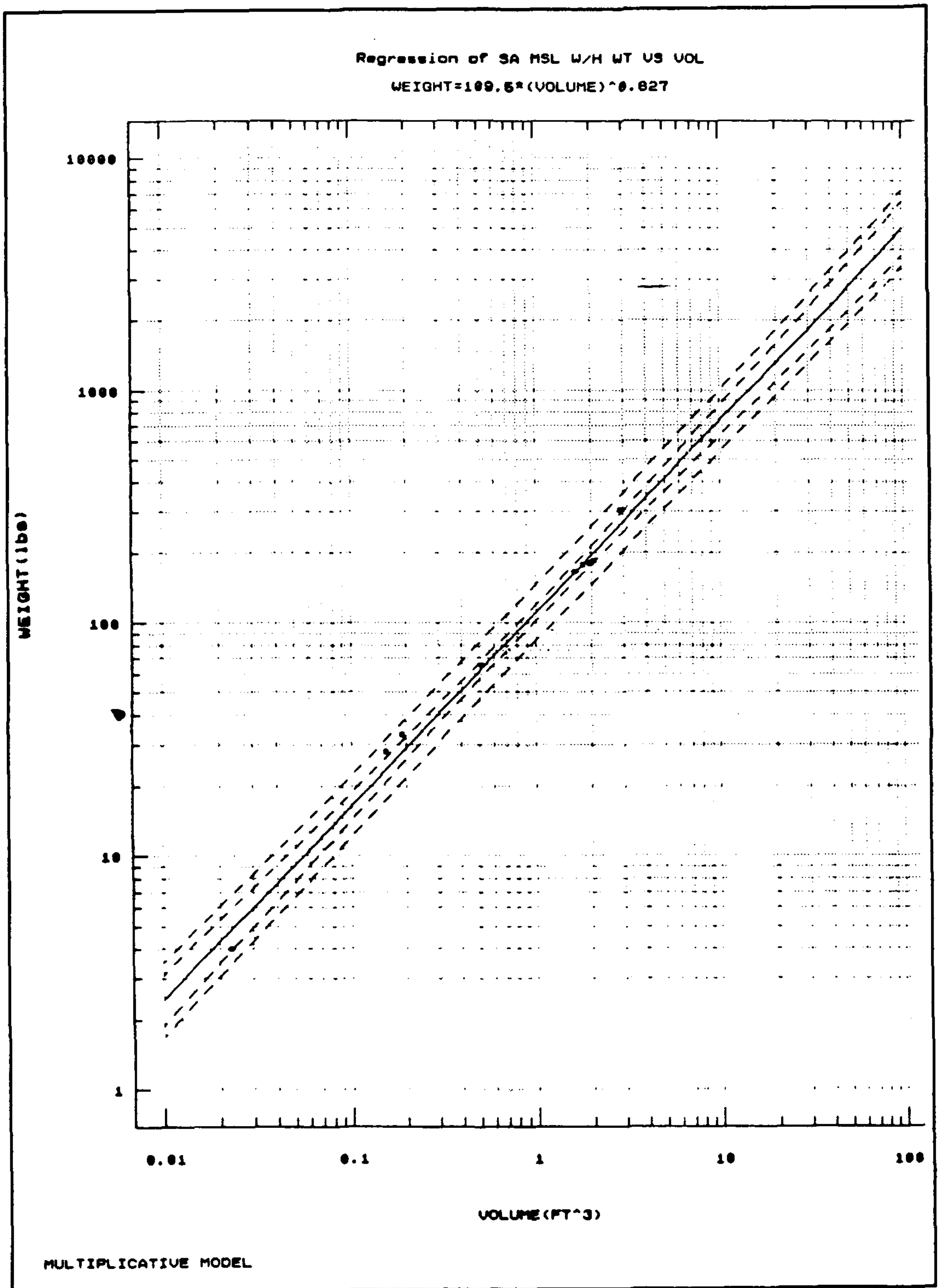

Figure B-73: SAM W/H Weight vs W/H Volume

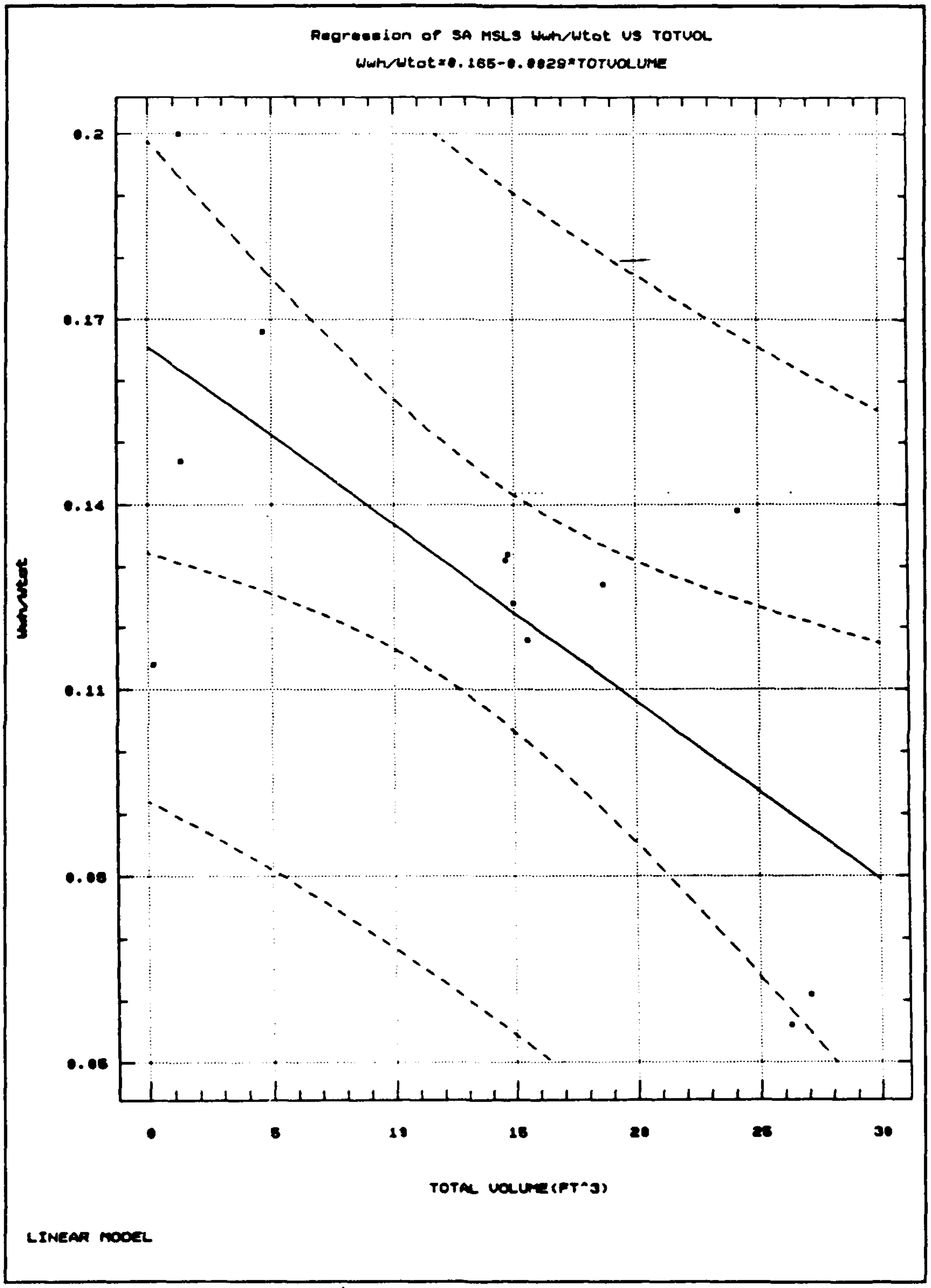

Figure B-74: SAM Wwh/Wt vs Volume

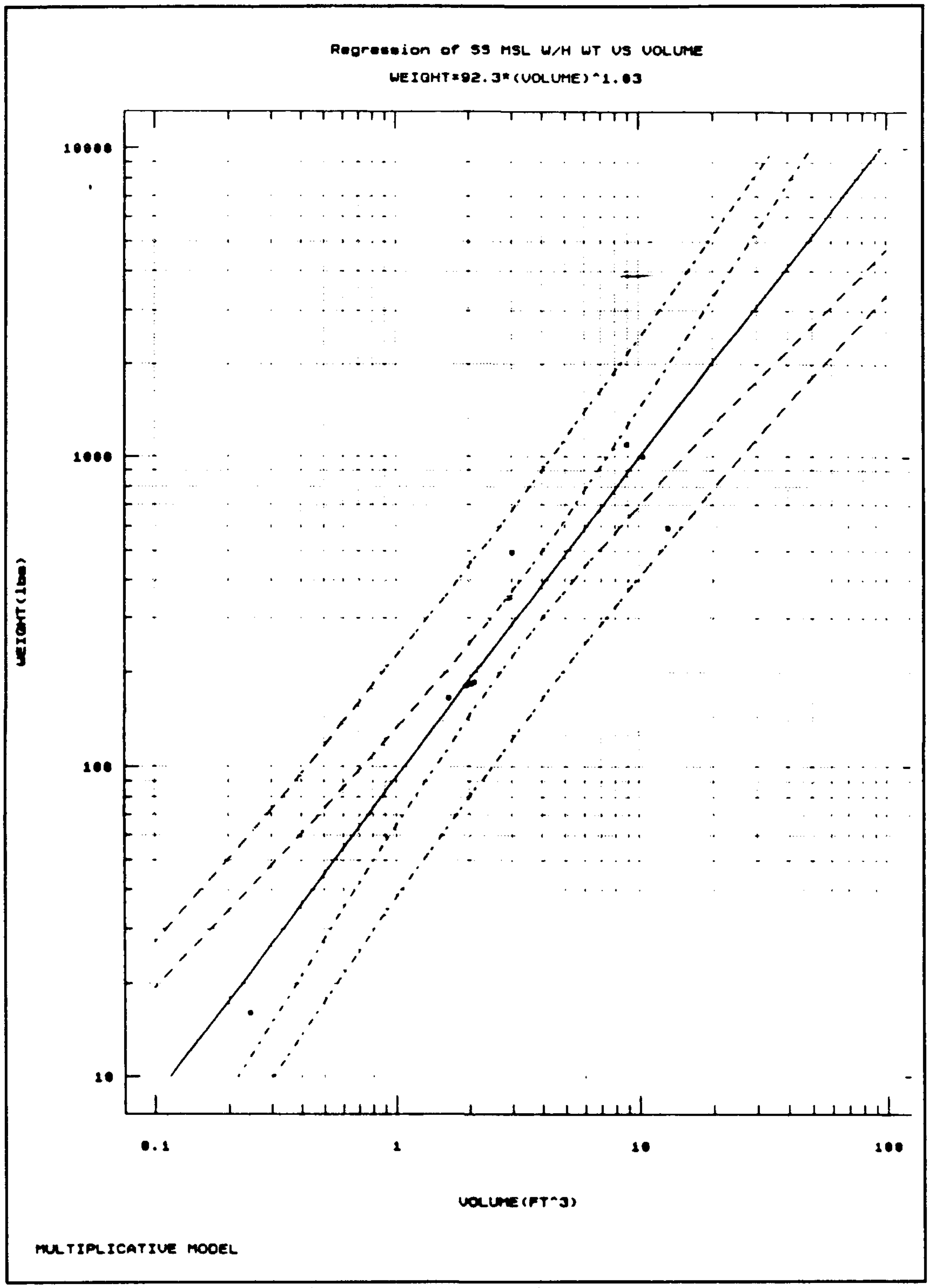

Figure B-75: SSM W/H Weight vs W/H Volume

APPENDIX C - VARIABLE COMBINATIONS

A. MULTI-VARIABLE SUBSECTION ANALYSIS

For the multi-variable subsection portion of the analysis, the following combinations of variables were considered:

- L D W
- L D W V
- L D W V RNG
- L D W V RNG DENS
- L D W V DENS
- L D W DENS
- L D W DENS RNG
- D W
- D W V
- D W V RNG
- D W V RNG DENS
- D W DENS
- D W DENS RNG
- L W
- L W V
- L W V R
- L W V RNG DENS
- L W V DENS
- L W DENS

- L W DENS RNG
- W V
- W V RNG
- W V RNG DENS
- W V DENS

With the addition of a model constant for each combination, the total number of combinations considered was 48.

B. MULTI-VARIABLE WING/FIN ANALYSIS

The following combinations of variables were considered during the multi-variable wing/fin portion of the analysis:

- W AR
- W TR
- W SWP
- W AR TR
- W AR TR SWP
- W SWP AR
- W SWP TR
- AR TR
- AR TR SWP
- TR SWP
- AR SWP

With the addition of a model constant for each combination, the total number of combinations considered was 22.

LIST OF REFERENCES

Data Search Associates, *U.S. Missile Data Book*, 1992, Sixteenth Edition, 1992.

Devore, J.L., *Probability and Statistics for Engineering and the Sciences*, Brooks/Cole Publishing Company, 1987.

Chin, S.S., *Missile Design*, McGraw Hill, New York, 1961.

General Dynamics Corporation, *The World's Missile Systems*, Eighth Edition, August 1988.

Naval Air Warfare Center, Weapons Division (Mr. Dale Knutsen) Unclassified Facsimile to LT John Nowell, NPGS, Subject: Missile Physical Characteristics and Comments, 12 March 1992.

Redmon, D.R., *Tactical Missile Design*, Engineer's Thesis, Naval Postgraduate School, Monterey, California, September 1980.

Society of Allied Weight Engineers Paper 762, *Constrained Regression Analysis-A New Approach to Statistical Equation Development*, by R.N. Staton, 8 May 1968.

Society of Allied Weight Engineers Paper 1497, *Missile Body Weight Prediction*, by J.R. Atkinson and R.N. Staton, 19 May 1982.

Society of Allied Weight Engineers Paper 1760, *Sizing Missile Guidance Systems*, by J.L. Pierson, 20 May 1987.

Statistical Graphics Corporation, *STATGRAPHICS Quickstart Guide Version 5*, 1991.

Statistical Graphics Corporation, *STATGRAPHICS Reference Manual Version 5*, 1991.

INITIAL DISTRIBUTION LIST

1.	Defence Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 52 Naval Postgraduate School Monterey, California 93943-5000	2
3.	Conrad Newberry Code AA/Ne Department of Aeronautics and Astronautics Naval Postgraduate School Monterey, California 93943-5000	3
4.	M.B. Jackson Advanced Systems Concepts Office Research, Development, and Engineering Center U.S. Army Missile Command Redstone Arsenal, Alabama 35898-5242	1
5.	Dale Knutsen Code 35P Weapon Systems Planning Office Attack Weapons Department China Lake, California 93555-6001	1
6.	John Nowell Jr.,LT.,USN 10 Conservancy Court Hilton Head Island, South Carolina 29926	1